The potential of sustainable agricultural practices to enhance soil carbon sequestration and improve soil quality

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Date: 20 February 2010

VERKLARING

Deur hierdie tesis elektronies in te lewer, verklaar ek dat die geheel van die werkhierin vervat, my eie, oorspronklike werk is, dat ek die outeursregeienaar daarvan is (behalwe tot die mate uitdruklik anders aangedui) en dat ek dit nie vantevore, in die geheel of gedeeltelik, ter verkryging van enige kwalifikasie aangebied het nie

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ABSTRACT

Sustainable agricultural management practices have a profound impact on soil carbon sequestration. The amount of carbon that can be stored in a given soil is influenced by climate, soil type, and the quality and quantity of organic inputs. Together, the interactive effect of these factors determines the Soil Organic Content (SOC). Sustainable agricultural management practices influencing Soil Organic Matter (SOM) include application of organic amendments, conservation tillage, and use of cover crops, crop rotations, crop residue management, and nutrient management. Increasing SOC enhances soil quality, reduces soil erosion, and increases agricultural productivity with considerable on-farm and off-farm benefits. To assess how management practices affect SOC, two case studies were conducted in Yavatmal district of Maharashtra in India and Lynedoch near Stellenbosch. The first case study examined the differences in SOC content on four farms each managed with 13 different sustainable agricultural techniques and one farm managed under conventional management practices. The second case study investigated the SOC differences between an organic and a conventional vegetable farm. The results of both studies show that farms that are managed under sustainable agricultural practices generally contain higher SOC content than farms that are managed under conventional agricultural practices.

OPSOMMING

Om te bepaal hoe bestuurspraktyke Grondlikke Organise Koolstoff raak, is twee gevallestudies in die distrikte Yavatmal in Maharashtra, Indië, en Lynedoch buite Stellenbosch uitgevoer. Die eerste gevallestudie het die verskille in Grondlikke Organise Koolstoff -inhoud bekyk op vier plase waar 13 verskillende Volhoubare landboubestuurspraktyke het 'n diepgaande impak op grondkoolstof-beslaglegging. Die hoeveelheid koolstof wat binne gegewe grond gestoor kan word, word deur klimaat, grondsoort en die gehalte en hoeveelheid organiese toevoer beïnvloed. Saam bepaal die interaktiewe effek van vermelde faktore die Grondlikke Organise Koolstoff -inhoud. Volhoubare landboubestuurspraktyke wat Grondlikke Organise Materiaal beïnvloed, sluit in die toediening van organiese verbeterings, bewaringsgrondbewerking, die gebruik van dekkingsoeste, oesrotasies, die hantering van oesresidu en voedingstofbestuur. Vermeerdering van Grondlikke Organise Koolstoff verhoog grondgehalte, verminder gronderosie en vermeerder landbouproduktiwiteit met aansienlike voordele op en verwyderd van die plaas. volhoubare landboutegnieke in die bestuurproses toegepas word, en een plaas wat volgens konvensionele bestuurspraktyke bedryf word. Met die tweede gevallestudie is ondersoek gedoen na die Grondlikke Organise Koolstoff -verskille tussen 'n organiese en 'n konvensionele groenteplaas. Die uitslae van albei studies dui daarop dat plase wat volgens volhoubare landboupraktyke bestuur word oor die algemeen hoër Grondlikke Organise Koolstoff-inhoud aantoon in vergelyking met plase wat volgens konvensionele landboupraktyke bedryf word.

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ACRONYMS

SOM	Soil Organic Matter
SOC	Soil Organic Carbon
Pg C/ yr	Petagram $=10^{15}$ g per year
FSGs	Farmers Study Groups
RMPs	Recommended Management Practices
FYM	Farm Yard Manure

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1 : INTRODUCTION

This chapter contextualizes the study. It begins by discussing the problem and its relevance and importance. It continues by presenting the research objectives and the main questions, which this study addresses. It concludes with a brief overview of the thesis structure.

1.1 Background of the study

There is a growing concern globally about the increase in greenhouse gases and their potential effects on global climate change (Intergovernmental Panel on climate Change, IPCC, 1996). Carbon dioxide (CO_2) the greenhouse gas of primary concern is been enriched into the atmosphere at a rate of 3.3 Pg C/yr. This rate has more than doubled since 1990 and continues to increase. The accumulation of CO_2 has been reported to be due to human activities, which include fossil fuel combustion, deforestation, land-use changes, soil degradation, and unsustainable agricultural practices. Agriculture, which is profoundly dependent on climate phenomena, provides both sources and sinks of greenhouse gases.

According to FAO (2003:334), agriculture worldwide contributes about 30 percent of the total anthropogenic emissions of greenhouse gases, accounting for 15 percent of the total anthropogenic sources of carbon dioxide (CO_2), 49 percent of methane (CH_4), and 66 percent of nitrous oxide (N_2O). The agricultural sector‘s contribution to carbon dioxide emissions is through direct and indirect mechanisms. (i) Indirect emissions emanate from the energy-intensive mining and production of agricultural inputs, (ii) direct emissions results from agricultural activities such as tillage as well as inappropriate land-use and soil mismanagement which: (a) increases the rate of decomposition of Soil Organic Matter (SOM), (b) reduces the quality and quantity of biomass return to the soil, and (c) carbon dioxide emissions from biomass burning and the use of fossil fuels in farm operations.

The soil is a significant source of atmospheric carbon dioxide. The estimates of the carbon released from world soils to the atmosphere ranges from 40-50 Pg (Lal, Kimble & Follett, 1997:7; Lal, Kimble & Follett, 1998:8). Losses of soil carbon from a wide variety of soils under cultivation are in the range of 20 to 30 percent of the carbon originally present (Lal *et al*, 1997:9). The entrenched trend of loss of carbon from soils can be reversed through soil carbon sequestration, achieved through the adoption sustainable agricultural practices, which are aimed at increasing SOC by increasing the primary production and input of organic matter to the soil. Estimates of the potential of carbon sequestration vary widely. The most recent global estimate is that of Lal (2004) 0.9 ± 0.3 Pg C/yr. The quantities of carbon that can be sequestered during the next century are enough to offset 2 or 3 decade's worth of carbon emissions at the current rate. The terrestrial uptake of carbon dioxide from the atmosphere will also serve as a way of reclaiming back the 150 or more Pg carbon lost to the atmosphere from vegetation and soils since 1850 as consequence of land use changes (Metting, Jacobs, Amthor & Dahlman, 2002:5). Increasing the storage of carbon in vegetation and soil potentially offers significant accompanying benefits including improving soil quality, sustainable productivity, decreased pollution of surface and groundwater by agricultural chemicals, reduced soil erosion, and overall off-site environmental degradation (Lal, McSweeny, Dick & Bartels, 2001:9).

In light of the above, it is in our best interest and the interest of the future generations to adopt sustainable agriculture intended to enhance soil quality and soil carbon sequestration. This is important not only to bring balance to the global carbon cycle but also in restoring the ecological functions of soils on which terrestrial life is dependent. Accordingly, this study discusses the potential of sustainable agriculture for increasing carbon sequestration and soil quality in agricultural soils.

1.2 Research Objectives and research questions

The main objective of this study is to investigate and compare the potential for soil carbon sequestration in conventional and sustainable agricultural production systems in two study areas, Lynedoch near Stellenbosch and Maharashtra in India. This study investigates and compares the management practices employed on the different farms. The study further investigates to what extent factors such as topography and soil conditions affect the overall SOC content and establish which of the agricultural management practices promote greater farm complexity and diversity.

The specific critical questions, which form part of the overall questions, will be specified at the beginning of each case study. Below are the general questions that the study seeks to answer:

1. How do organic and conventional management practices affect SOC?
2. What other factors except management practices affect SOC?

3. Which farms are more complex and diverse, sustainable, or conventional farms?

1.3 Outline of the study

This thesis is organized into five chapters. Chapter 2 reviews the relevant literature on carbon sequestration, and discusses and compares management practices employed on conventional and organic farm systems, and distinguish how these practices affect the SOC content, soil quality and the overall sustainability of the farm. Chapter 3 is the India case study. The study introduces sustainable farming techniques adopted by Indian farmers. It investigates the effect of the management practices on SOC by comparing four farms managed under sustainable agricultural techniques and one farm managed under conventional agricultural practices. The study compares the SOC levels between the different farms. Chapter 4 is the Lynedoch case study, which compares management practices between a conventional and an organic vegetable farm and distinguishes how these affect the SOC. Chapter 5 is the conclusion of the thesis.

The terms SOC (soil organic carbon) and SOM (soil organic matter) will be used interchangeably throughout the thesis with an understanding that SOC is approximately 58% of SOM.

Sustainable agriculture is a range of philosophies comprise of ecological, organic, biodynamic, humus, low external input, resource conserving and the regenerative system (Badgley, 2006:94). In that respect, the term sustainable agriculture and organic agriculture will be used interchangeably throughout the thesis.

CHAPTER 2 : THE INFLUENCE OF SUSTAINABLE AGRICULTURAL MANAGEMENT PRACTICES ON SOIL CARBON EMISSIONS AND SOIL CARBON SEQUESTRATION

2.1 Introduction

Soil carbon sequestration can be achieved by promoting a net flux of carbon from the atmosphere into stable soil carbon pools, where it is held in the form of SOM. Sustainable agricultural practices enhance levels of SOC. Soil carbon sequestration comes with significant benefits of improved soil quality, enhanced soil biodiversity, improved food, and fibre production and mitigation of global climate change. This chapter commence by discussing the soil constituents, these are soil components, which interactively affect SOC, soil quality and soil carbon sequestration. The discussion will focus more on the organic constituent, which is a dynamic component responsible for soil carbon sequestration and soil quality. This is followed by practices and processes that reduce the soil carbon pool and those that increase the soil carbon sink.

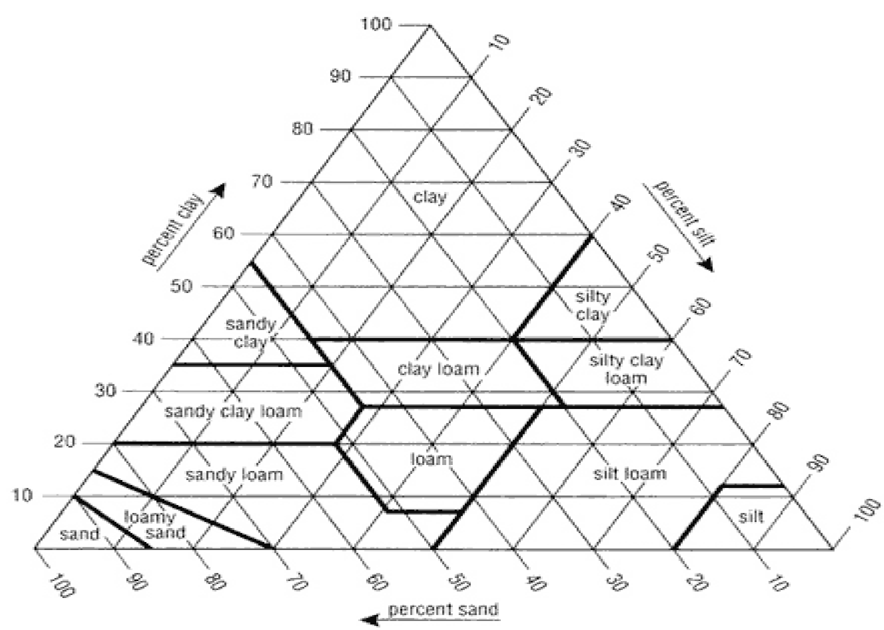
2.2 Soil constituents

In terms of soil constituents, the soil can be viewed as a three-phase system comprising of solid, liquid, and gaseous constituents. The solid phase consists of both minerals and organic material. The mineral fraction is derived largely from the parent material that decomposed by weathering and by biological activities. The organic fraction is largely from vegetation growing in and above the soil (Lengeler, Drews & Schlegel, 1999:780).

2.2.1 The mineral component

The mineral component of the soil which is about half of the soil's volume (Uphoff, Ball & Fernandes, 2006:4) differs in different soils in its chemical composition and physical characteristics. These minerals exist in different particle sizes, which may be classified into sand, silt or clay. The *USDA* soil texture classes are sand, loamy sands, sandy loams, loam, silt loam, silt, sandy clay loam, clay loam, silty clay loam, sandy clay, silty clay, and clay. Subclasses of sand are subdivided into coarse sand, sand, fine sand, and very fine sand. Subclasses of loamy sands and sandy loams that are based on sand size are named similarly (FitzPatrick, 1978:88). Soil texture is an inherent property that influences many other soil properties such as water holding capacity, infiltration capacity, buffer capacity, aeration and the cation-exchange of the soil.

Figure 1: The USDA Soil Classes



Source: Ashman & Puri, 2008:28

Sandy soils are characterized by macropores, which allow rapid movement of water, air and provide space for roots and organisms to inhabit the soil. Sandy soils have low cation-exchange, buffer capacity, nutrient retention, and water holding capacity. They are therefore likely to be droughty and lacking in fertility. Silt soils are intermediate in texture and consist almost entirely of micropore spaces too small to allow rapid movement of air, and pores are likely to become waterlogged. Finely-textured clay soils with even smaller pore spaces can easily have inadequate aeration and poor drainage leading to water logging. Soils of this type are very sticky when wet and very hard when dry, making management difficult. However, clay soils have a high moisture and nutrient holding capacity. Generally, medium-textured soils that have a balance between aeration, water and nutrient holding capacity are most suitable for agriculture.

2.2.2 The liquid component

The properties of the soil liquid phase reflect the range of environmental factors, which determine chemical conditions in the ecosystem (Snakin, Prisyazhnaya & Kovacs-Lang 2001:17). It constitutes approximately one quarter of the soil volume, although the actual amount varies greatly over time and between different soils (Uphoff *et al*, 2006:4). The liquid component, derived from precipitation and ground-water sources, is able to transport materials through the soil in both suspended and dissolved form (Soil and environment, 1995:9). The liquid component is the direct substrate for uptake of nutrients by plants and microorganism.

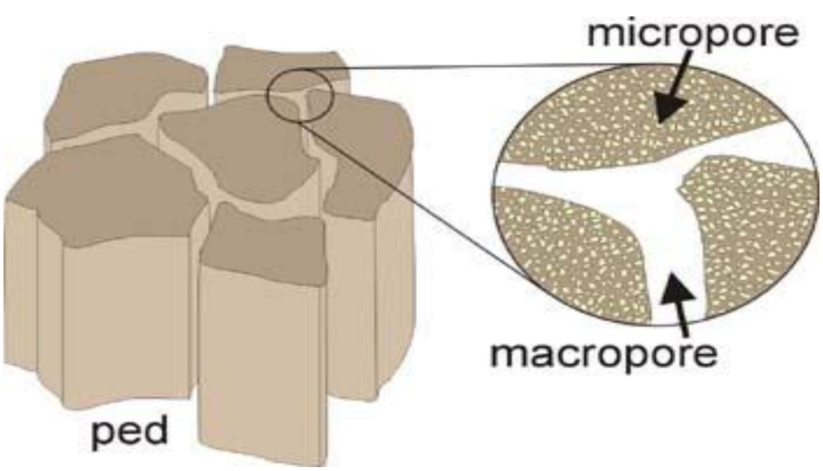
2.2.3 The gaseous phase

The gaseous component, also known as the soil atmosphere, consists of mixtures of gases including oxygen, hydrogen, nitrogen, carbon, ammonium, and water derived from the above-ground atmosphere and from the respiration of soil organisms (Soil and environment, 1995:9; Certini, Scalenghe & Ugolini, 2006: 76). The soil atmosphere fills the water-free pore space and interacts with the soil liquid and solid phases.

2.2.4 Soil porosity

The more pore space within the soil, the greater will be its capacity for holding both water and air, which benefit plants as well as other flora and fauna in the soil. For any given soil porosity, the amount of water and air are usually inversely related (Uphoff *et al*, 2006: 4). Pore sizes in the soil may be divided into macropores (d>0.08mm) and micropores (d<0.08mm).

Figure 2: The Soil Pore



Source: SoilWeb http://www.landfood.ubc.ca/soil200/interaction/water_air.htm

Macropores can represent as much as a third of the total porosity of the soil. Pores in this size class span range in sizes and include biopores shrinkage, cracks and other inter- aggregate pores, and the larger pores within the aggregates and peds. These pores have a major influence on a range of soil characteristics such as aeration, water, and solute flow, as well as on root development (Lal, Bobby & Steward, 1998:180). Soil micropores provide a "storage volume" that can protect solutes against leaching and diffusion out of the soil. Micropores help to supply nutrients to plant roots (Lal, 2006:1353).

2.3 The organic component

The organic fraction of the soil usually comprises only a small portion of the soil by volume, usually between 1 and 6 percent, although it can be higher than this (Uphoff *et al*, 2006:4). SOM according to Schlesinger (1997) is an important driving force in environmental global change as it acts as both a source and sink of atmospheric carbon and plays a critical role in soil processes. Organic matter on the surface of the soil (mulch) has the function of protecting the soil from harsh environmental and climatic conditions. Below the soil, organic matter forms what is known as the SOM. SOM is a key component of the soil, affecting and influencing its chemical, biological, and physical properties. Increasing the content of SOC enhances soil quality, reduces soil erosion, improves water quality, and increases biomass and agronomic productivity (Kimble, Lal & Follet, 2002:4). SOM is derived from soil biomass and it consists of both living and dead organic matter.

2.3.1 Dead SOM

The dead SOM is formed by chemical and biological decomposition of organic residues. Dead SOM can be distinguished into (1) organic matter in various degrees of decomposition but in which the morphology of the plant and animal materials are still visible, and (2) completely decomposed materials. Some of the compounds are non-humified, whereas others are humified compounds. The non-humified compounds are released by the decay of plant, animal and microbial tissues in their original or in slightly modified form. They include protein-like substances, hemicellulose, cellulose, organic acids, carbohydrates, gums, waxes, fats, lignin, miscellaneous tannins, glucosides, alkaloids, pigments, and a variety of organic acids (Tan, 2000:80). These compounds constitute the energy supplying food of soil microorganisms (Allison, 1974:143). They are easily decomposed by microorganisms as compared to humic substances, which take time to decompose. The humified compounds are products that have been synthesized from these non-humified substances by the process of humification. They consist of groups of complex substances such as fulvic acids, humic acids and humins, which are generally resistant to further biological decomposition (Lampkin, 2003:54).

2.3.1.1 The non-humified compounds

2.3.1.1.1 Carbohydrates

The significance of carbohydrates in soil arises largely from the ability of complex polysaccharides to bind inorganic soil particles into stable aggregates (Stevenson, 1994:142).

Carbohydrates also form complexes with metal ions, and they serve as building blocks for humus synthesis. The chemical behaviour of monosaccharide and polysaccharides is largely a function of their reactive hydroxyl and carboxyl groups. In polysaccharides especially, the abundance of such groups and the linear configuration provide ample opportunity for interaction with metals and with inorganic colloids (Schnitzer & Khan, 178:84). Carbohydrates are also substrates of most soil microbial organisms and provide energy that drives biochemical processes in the soil.

2.3.1.1.2 Proteins and amino acids

Proteins and amino acids are the most important nitrogenous organic compounds found in the soil. It is estimated that 20 to 50 percent of organic nitrogen in soil exists as amino acids. Amino acids are precursors of phytohormones. LMethionine, a precursor of growth factors, stabilizes the cell walls of the micro flora (Frankenberder, Jr, & Arshad, 1995:408). This facilitates the assimilation of nutrients. The polymerization of amino acids produces chain polymers known as polypeptides, very long chains of polypeptides are known as proteins.

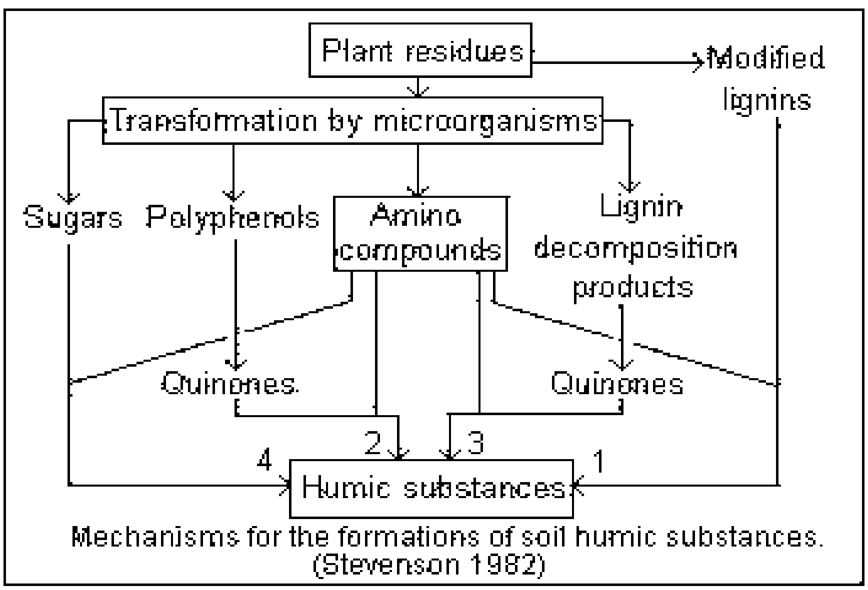
2.3.1.1.3 Lipids

Lipids are important components in SOM due to their hydrophobic nature and their high reactivity toward polyvalent cations. They influence aggregate stability, water retention and fertility of soil (Huang, Bolleg & Senesi, 1991:113). Lignin is an important precursor of humic substances. According to existing humification theories, a significant part of the aromatic structure in humic substances originate from lignins (Sposito, 2008:54).

2.3.1.2 Complex humified compounds

Humic substances are dark-coloured, biologically refractory, heterogeneous organic compounds produced as the product of microbial metabolism (Sposito, 2008:70). Preliminary understanding about how humic substances are formed is based on four published theories: (1) Lignin modification, (2) Quinone Amino Acid Interaction, (3) Microbial Synthesis of Aromatics, and (4) The Mallard Reaction (a sugar amino acid reaction sequence), as shown in Figure 3.

Figure 3: Formation of Humic Substances



Source: http://www.ar.wroc.pl/~weber/powstaw2.htm

Each theory describes complicated biotic and abiotic reactions in which a variety of organic compounds, such as phenolic compounds (e.g. lignins), complex carbohydrates, and nitrogenous substances are re-synthesized to form large complex polymers. In order for these polymerization reactions to proceed, inorganic mineral catalysts must be present. Therefore, the availability of trace minerals is a requirement for the formation of humic substance (Stevenson, 1994:188). Three classes of substances are generally recognized, namely fulvic acid, humic acid and humin (Allison, 1974:143). They are the product of the humification process and have many vital functions in the soil.

2.3.1.2.1 Fulvic acid and function in the soil

Fulvic acid is the most plant-active of the humic acid compounds, it is a plant growth stimulator that improves root development. It is naturally produced in soil by composting and can rejuvenate the soil. Fulvic acid stimulates metabolism, provides respiration, increases metabolism of protein and activity of multiple enzymes, enhances permeability of cell membrane, cell division and elongation, acid chlorophyll synthesis, drought tolerance, crop yields, buffers soil pH, assist dendrification of microbes, contribute to electrochemical balance as a donor or an acceptor, decompose silica to release essential minerals, nutrients, detoxifies pollutant such as pesticides and herbicide (Hemat,2007:214). It is an excellent supplement to fertilizers to improve nutrient absorption. Fulvic acid not only has the ability to transport nutrients through cell walls, it can also sensitize cell membranes and has various other physiological functions.

2.3.1.2.2 Humic acid and function in the soil

The term humic acid is used to describe a brown-to-black organic substance extracted from soil, sediments, or other geological material with dilute alkalis (Wallace & Terry, 1998:474). Humic acids are larger than fulvic acids and contain higher percentage of aromatic groups (Becker, 2004:4). Humic acid complexes with metallic ions related to carboxyl (-COOH) and phenolic (-OH) groups in its structure, and thereby supplies nutrients (Schnitzer 1992).

2.3.2 The living component of SOM

Soil microbial biomass is the major living component of SOM. Although microbial biomass constitutes less than 0.5 percent (w/w) of the soil mass, it has major impacts on soil properties and processes (Mukerji, Manoharachary, Chamola, 2002:249). Soil micro-organisms play an important role in biogeochemical cycles upon which life on earth depends. The nutrient content of microorganisms exceeds that of plants (Newton, Edward & Niklaus, 2006:16). Microbial biomass is considered a bio-indicator of soil quality.

The soil ecosystem contains an enormous number of organisms, which exist in a complex heterogeneous mixture. Microbial diversity in soil ecosystems exceeds, by far, that of eukaryotic organisms. One gram of soil may harbour up to ten billion microorganisms of possibly thousands of different species (Varma, Abbott, Lynette, Werner, & Hampp, 2007:71).

2.3.2.1 Classification of Soil Microbial Organisms

This wide range of living and non-living organisms enables the soil to provide supporting services that sustains and makes other vital ecosystem services possible. Soil organisms may be grouped into microflora, microfauna, mesofauna, macrofauna and megafauna. Microflora is a diverse group of non-animal organisms, namely: bacteria, actinomycetes, fungi, algae and plant roots. It is estimated that 60 to 80 percent of the total soil metabolism activity is due to the microflora. Not only do they destroy plant residues but they function in the digestive tracts of animals and eventually decompose the dead bodies of all organisms. Soil humus is one of the significant end products of their activities (Brady, 1974:115).

Soil fauna (micro, meso, and macro) are also a diverse group ranging from moderately large animals to those that cannot be seen with the naked eye. Microfauna are organisms <100µ in width, these are; nematoda, rotifera and protozoa. These are aquatic organisms that exist in water films and particle surfaces in the soil (Gregorich & Carter 1997:93). Soil mesofauna are animals with a width that range from 100 to 2000 µm. This group consists of mites, collembola and other small insects, spiders and enchytraeidae.

Soil macrofauna and megafauna (animals >2000 µm) are the most conspicuous soil animals and have the greatest potential for direct effects on the soil functional properties. These animals include ants, termites, amphipoda, isopoda, centipedes, millipedes, adult and larval insects, earthworms and some vertebrates.

2.3.2.1.1 Bacteria and Fungi

Soil bacteria and fungi are important in developing and maintaining soil structure and aggregation. Different soil bacteria and fungi produce enormous variety of enzymes such as dehydrogenase, proteases, and cellulases that are secreted into the surrounding environment. These exoenzymes reduce organic molecules and degrade protein and cellulose respectively into their component parts outside the cell. Soil bacteria improve soil structure by producing exopolysaccharides and other metabolites that help glue soil particles together. Fungi, by producing a network of hyphal filaments, also help to stabilize aggregates (Uphoff *et al*, 2006:71-74). In addition, Lampkin (2003) proposed that fungal hyphae might work in the same way as plant roots, mechanically pressing soil particles together.

2.3.2.1.2 Protozoa

Protozoa are grazers and feed on other soil microorganisms especially bacteria. Protozoa predation on bacteria was found to hasten the turnover of readily available nutrients (Brady, 1974:121). Protozoa are the most varied and numerous of the microbes, and play an important role in mineralization and immobilization of nutrients, nitrogen, phosphorus and sulphur.

2.3.2.1.3 Nematodes

Nematodes play a minor role in organic matter breakdown, since they do not feed largely on dead plant tissues. They do, however actively feed upon microorganisms that live on decaying plant tissues and thus affect the total microbial activity and ecological relationships (Allison, 1974:61). They also play a key role in nutrient cycling, although plant-parasitic nematodes are a serious agricultural pest, the many other groups of nematodes are very beneficial within the soil.

2.3.2.1.4 Earthworm

Earthworms may be considered the most important soil fauna, as they dramatically affect soil structure, nutrient cycling, water and air movement. All earthworm species contribute to the breakdown of plant litter but differ in the way in which they degrade organic matter.

Their activities can be of three kinds, each associated with a different group of earthworm (Edwards, 2004:328). Some species are limited to the soil surface, some live just below the soil surface and some live exclusively in organic matter and cannot survive for long in the soil. The last group, which includes the species *Eisenia fetida*, are mainly used in vermiculture and vermicomposting.

According to Brady (1974), the amount of soil these creatures pass through their bodies annually amounts to as much as 15 tons of dry earth per acre. Earthworms ingest soil and litter and mix them thoroughly while adding significant amount of water (1 vol. of water for 1 vol. of soil) and intestine mucus that act as an ecological mediator similar to that exudates (Varma,2005:295). The muscular contraction of the earthworm crop and gizzard, the peristalsis of the gut wall, and construction of the body wall creates a great range of pressure that mechanically disrupts soil microaggregates during passage through the digestive tract (Edward, 2004:185). As organic matter passes through the guts of earthworms, it is fragmented and inoculated with microorganisms thus increasing the microbial activity. This facilitates the cycling of nutrients from organic matter and their conversion into forms readily taken up by plants.

Earthworm casts can be distributed at the soil surface or at depth. Research has established that casts are higher in bacteria and organic matter, total and nitrate nitrogen, exchangeable calcium and magnesium, available phosphorus and potassium, pH, percentage base saturation and cation-exchange capacity (Brady, 1974:117).

The truly soil-inhibiting species have permanent burrows that penetrate deep into the soil. These species feed primarily on organic matter but also ingest considerable quantities of inorganic material and mix these through the soil profile. These species are of primary importance in pedogenesis (or soil formation) which is influenced through the movement of organic and mineral material through soil depth. Charles Darwin (1881) calculated that earthworms can move large amounts of soil from the lower strata to the surface and also carry organic matter down into deeper soil layers, in some field he observed that 0.2 inches (about 30 tons per acre) of soil is brought to the surface per year over a 25 year period and in the process bury stones, ciders and other foreign bodies (Allison, 1974:63).

The burrows left by earthworms are bigger and more stable than other pores formed by most other organisms in the soil and tend to remain open and continue to function as preferential flow paths. This increases soil aeration and drainage and more over the earthworm through their deep burrowing activity are able to bring lower soil to the surface.

Earthworms influence nutrient cycling in four ways, (1) during transit of litter through guts, (2) in freshly deposited earthworm casts, (3) in aging casts, and (4) during the long-term genesis of the whole soil profile (Magdoff & Weil, 2004:333). Many of the influences of earthworm on nutrient cycling processes and mineralization of organic matter are mediated by the mediation between earthworms and microorganisms (Edward & Bohlen, 1995:162).

2.4 The role of SOM on Soil Quality

SOM has an important influence on the chemical and physical properties of the soil and is one of the key components for assessing soil quality (Roose, Lal, Feller, Barthes & Steward, 2007:37). Some of the effects of SOM are given in Table 1. The addition of organic material to soil usually leads to a cascade of cause-and-effect relationships that produces a series of changes to soil properties and processes (Magdoff & Weil, 2004:28).

Table 1: General properties of Soil Organic Matter and associated properties

Property	**Remarks**	**Effect on soil**
Colour	The typical dark colour many soils are caused by organic matter.	May facilitate warming
Water retention	To Organic matter can hold up 20 times its weight in water	Helps prevent drying and shrinking. May significantly improve moisture retaining properties of sandy soil.
Combination with clay minerals	Cements soil particles into structural units called aggregates	Permits exchange of gases stabilizes structure, increases permeability

Chelaton	Form stable complexes with CU^{2+}, Mn^{2+} Zn^{2+} and other polyvalent cations.	May enhance the availability of micronutrients to higher plants
Solubility in water	Insolubility of organic matter is because of its association with clay. Also salts of divalent and trivalent cations with organic matter are partly soluble in water.	Little organic matter is lost by leaching
Buffer action	Organic matter exhibits buffering in slightly acid, neutral, and alkaline ranges	Help to maintain neutral pH in the soil.
Cation Exchange	Total cation exchange capacity of isolated fractions of humus range from 300 to 1400 mEq/100g.	Many increase the cation exchange capacity (CEC) of soil. From 20 to 70% of the CEC in many soils (e.g., mollisols) is caused by organic matter
Mineralization	Decomposition of organic matter yields CO_2, NH^+, NO^{3-}, PO^{4-}, and SO_4^{-2}.	A source of nutrient element for plant growth
Combines with organic molecules	Affects bioactivity, persistence and biodegradability of pesticides	Modifies application rate of pesticides for effective control

Source: Smith *et al*, 1993:68 citing Stevenson 1982

The quantity and quality of SOM impact many soil functions related to soil health, such as moisture retention, infiltration and nutrient retention and release (Magdoff & Weil, 2004:132). The dynamic nature and complex chemistry of SOM makes it a major source of plant nutrients, with 95 percent of soil nitrogen, 90 percent of soil sulphur, and 40 percent of soil phosphorus, being associated with the SOM fraction. Decomposition and turnover can supply most macronutrients needed for plant growth (Kimble, Rice, Reed, Mooney, Follet & Lal, 2007:155).

Being a source of mineral nutrients, it contributes to soil chemical fertility and act on soil physical fertility through its role on soil structure.

The emphasis on sustainable agriculture and more generally on sustainable land use, initiated the development of soil quality concept during the 1990s (Bloem, Hopkins & Benedetti, 2006:50). The soil quality concept addresses the associations among soil management practices, observable soil characteristics, soil processes, and the performance of soil ecosystem functions (Magdoff & Weil, 2004:2). In simple terms, it is proposed as a tool of assessing the sustainability of managed farm and soil systems.

Sustaining soil quality is the most effective method for ensuring sufficient food to support life as we know it (Seybold, Mausbach, Karlen & Rogers, 1998:387). Soil quality is not solely limited to productivity but goes beyond to encompass other ecological soil functions that are crucial in maintaining soil sustainability.

Soil quality has been defined as the "fitness to use". The National Academy of Sciences in its publication-*Soil and Water quality: An Agenda for Agriculture* defined soil quality as the "capacity of the soil to function" (National Research Council, 1993). Seybold *et al* (1998) in his paper used the definition of soil quality by Karlen *et al*. (1997b) "The capacity of a specific kind of function, within natural or managed ecosystem boundary, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation (Seybold, *et al*, 1998:388).

Likewise NRC (1993) defined soil quality as "the capacity of a soil to function, both within its ecosystem boundaries (e.g., soil map unit boundaries) and with the environment external to that ecosystem (particularly relative to air and water quality)" (NRC, 1991:176). According to Bloem *et al* (2006) the phrase “ecosystem boundaries” implies that each soil is different (Bloem, *et al*, 2006:23). Therefore, management practices to be employed in that particular area must coincide with the soil texture and the climatic conditions (moisture and temperature) of that area. In this paper soil quality is defined as the soil suitability to perform ecosystem functions (e.g. food and fibre production, carbon sequestration).

Soil quality is determined by a combination of physical, chemical, and biological properties such as texture, water-holding capacity, porosity, organic matter content, and depth. Since these attributes differ among soils, soils differ in their quality (NRC, 1993:191). SOC is one of the main component and basic parameter for soil quality, since SOC content correlates strongly with many soil properties and functions (Roose, *et al*, 2007:73). The beneficial impacts of SOC on soil quality are attributed to: (1) stabilization of soil structure through formation of organo-mineral complexes, and development of stable aggregates; (2) improvement of water-holding capacity of the soil through increase in soil moisture retention at field capacity; (3) improvement in soil biodiversity especially activity of soil fauna (e.g. earthworms); (4) biodegradation of contaminants; (5) buffering of soil against sudden changes in pH and elemental concentrations, (6) minimizing leaching losses of fertilizer through chelation adsorption; (7) filtering and purification of water by absorption and degradation of pollutants; (8) strengthening mechanisms of elemental cycling ;(9) improving soil quality and crop productivity; and (10) sequestering carbon and mitigating climate change (Lal,2006:25). In order to maintain soil quality, practices that promote and protect SOM need to be adopted and sustained, and practices that accentuate the release of CO_2 from soil need to be avoided. Management practices that enhance soil quality and promote soil carbon sequestration will be discussed later in the chapter.

2.5 The role of SOM in soil aggregate stability

Soil aggregation and SOM are intimately associated with each other, and any change in either of these factors will often result in feedback on the other. Soil aggregate is defined by Lal (2006) as conglomeration of organic and inorganic particles that cohere to each other more than the neighbouring particles. As proposed by Edward & Bremner (1967) two size classes of soil aggregates exist and they are macroaggregates >250 µm diameter and microaggregates <250 µm. Factors that affect soil aggregate formation include particle size, wetting and drying, freezing and thawing, cultivation, microorganism, earthworms and plant growth (Allison, 1974:318). There are several options to enhance aggregation including the use of long chain polymers and soil conditioners, enhancing activity and species diversity of soil fauna, enhancing bioturbation, and growing plant species with extensive and deep root system (Lal *et a*l,1995b:376). Roots influence aggregates physically both by exerting lateral pressure and by continuously removing water during plant respiration, leading to drying of the soil and cohesion of soil particles around the roots (Coleman, Crossly & Hendrix, 2004: 72). Microorganisms influence the soil aggregation in two ways (1) by holding the soil particle together by adhesion and by mechanical binding and (2) by the production of polysaccharides and other organic substances that act as glues or cements (Allison, 1974:316).

Aggregate stability is influenced by organic binding agents, poly-cation bridging, organism glues, or organic–inorganic bonds, thus creating structures that entrap organic matter and protect it from decomposer organisms and their extracellular enzymes (Roseburg & Izaurralde, 2001:75). These organic gluing agents have different degrees of bond stability.

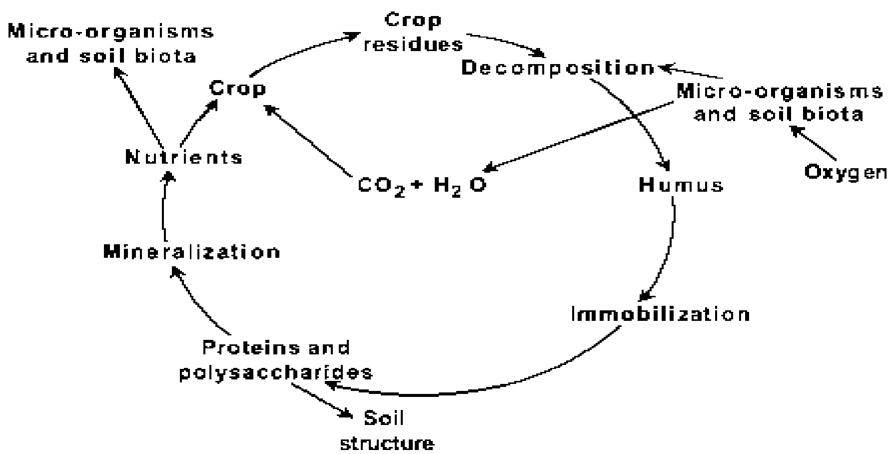
Glomalin is also thought to play an important role in aggregate stability (Buscot & Varma, 2005:112). Glomalin is a moderately stable component of SOM with a mean turnover time reported to range from 6 to 40 years (Cardon & Whitebeck, 2007:135). Glomalin is a green, tough sticky substance produced by hyphae and spores of arbuscular mycorrhizal fungi in soils and roots. Glomalin, a glycoprotein may be an important specific cementing agent involved in the aggregation process. As a glycoprotein, glomalin stores carbon in both its protein and carbohydrate (glucose or sugar) subunits containing between 30 to 40 percent carbon by weight and 1 to 9 percent of tightly bound iron. Higher levels of atmospheric carbon stimulate the growth of glomalin-producing fungi and consequently the level of glomalin in the soil (Nannipieri & Smalla, 2006:107). In addition to improving aggregate stability, glomalin enhances nutrient accessibility and because of high iron content, protects the plants from pathogens and facilitates better crop production (Reiley, 2004:33). It also increases water infiltration and water retention.

The activities of soil microbes produce high molecular mass organic polymers, which serve as gluing agents and are involved in the formation and stabilization of soil aggregates (Lengeler & Schlegel, 1999:780). Soil aggregates are formed when mineral particles fuse with organic polymers produced by microorganisms. Tisdall and Oades (1982) and Oades (1984) classified the organic binding agents in three groups: transient, temporary and persistent materials. Transient binding agents are organic materials, which are decomposed rapidly by microorganisms. The most important group is polysaccharides, the effect of which lasts weeks. Temporary binding agents are roots and hyphae, particularly vesicular–arbuscular mycorrhizal hyphae, they persist for months or years and are affected by soil management. Persistent binding agents consist of degraded humic material associated with amorphous iron, aluminium and aluminosilicates (Lal, 1998:64).

2.6 The carbon cycle, CO_2 emission and sequestration

The carbon cycle is a complex series of cyclical processes occurring through biotic and abiotic systems. Carbon cycling is defined as a continuous transformation of organic and inorganic carbon compounds by plants and micro- and macro-organisms between the soil, plants and the atmosphere (Bot & Benites, 2005:94). The carbon molecule moves from one chemical state to another (simple chemical compound form e.g. CO_2 to complex chemical compound form e.g. $C_{187}H_{186}O_{89}N_9S_1$), from one physical location to another on the earth's surface in a closed loop. It is powered by solar energy in conjunction to earth's gravity and geochemical process (Socolow, 1997:121). Figure 4 gives a schematic outline of the carbon cycle.

Figure 4: The carbon cycle



Source: FAO, 2001:91

The carbon cycle usually initiates when carbon from the atmosphere is absorbed by plants and is transformed into carbohydrates, cellulose and other sugars through the process of photosynthesis. See chemical equation 1. Each year, photosynthesis of land plant takes approximately 120 Pg /yr from the atmosphere and the same amount is taken back to the atmosphere through respiration (Luo & Zhou, 2006:22). Carbon dioxide is also released to the atmosphere through decomposition and other ecosystem processes.

$$\underset{\text{Carbon dioxide}}{CO_2} + \underset{\text{water}}{H_2O} + \underset{\text{sun}}{\text{Energy}} \text{ ----------> } \underset{\text{represents Organic matter in plants}}{C_6H_{12}O_6} + \underset{\text{Oxygen}}{O_2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

Dead plant materials (and other carbon compounds) are broken up into simpler organic and inorganic molecules through the process of decomposition. Decomposition of organic matter is largely a biological process that occurs naturally. Its speed is determined by the following factors: activity of soil organisms, the physical environment, the quality of the organic matter, the chemical composition of substrate, moisture supply and temperature (Berg & McClaugherty, 2003:2 & 239). In the decomposition process, different products are released. CO_2 is the main by-product and is released in massive quantities into the atmosphere. Plant nutrients are also released as by-products of decomposition and through mineralization. These nutrients are transformed into soluble form to be taken up by plants. Other products of decomposition are water, energy, and re-synthesised organic carbon compounds. The organic carbon is stored in stable forms produced during the humification process and in other complex organic substances such as glomalin, which is produced by microorganisms.

According to Reicosky *et al, (*2000) carbon dioxide is released into the atmosphere through plant and microbial respiration at a rate of approximately 1.5 Pg/year. Of total carbon, only a fraction of the crop residue carbon is stabilized in SOM. The majority is returned to the atmosphere as carbon dioxide from microbial respiration within a year or two of its addition to the soil (Magdoff & Weil, 2004:46-48). Some plant constituents such as lignin and other polyphenols take longer time to be decomposed and as a result retard decomposition of plant residues. (Bot & Bernis, 2005:95). Decomposition of polysaccharide compounds such as sugars, starches, and proteins is rapid, taking place within hours, and decomposition of cellulose, fats, waxes, and resins is moderate. Carbon dioxide is also released into the atmosphere through burning and if oxygen is unavailable, carbon is retuned as methane (CH_4).

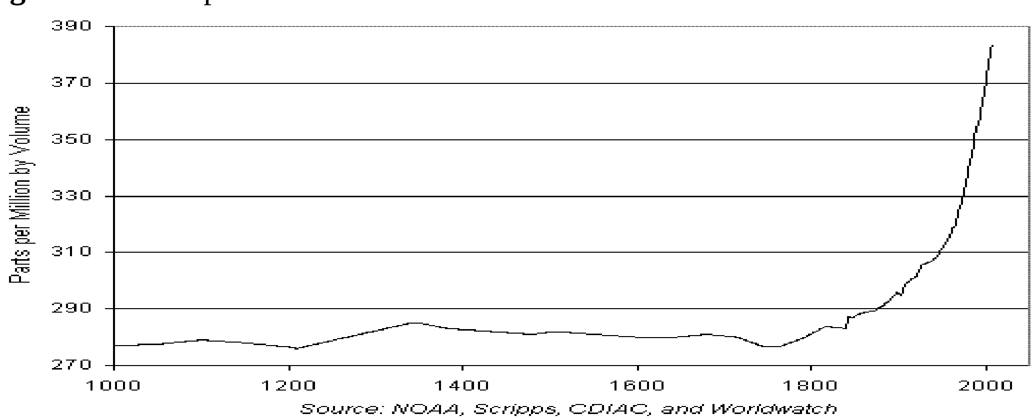
The carbon cycles like any other global cycle consist of major pools with fluxes between pools. The pools can act as sinks when they sequester carbon or sources when they release carbon (Smithson & Addison, 2002:394). Soils are the largest terrestrial pool of carbon. Globally soils contain approximately 1,500 Pg C and can act as either net sources or net sinks of atmospheric CO_2 (Izaurralde & Rosenberg, 2001:73). For a given soil type, SOC stocks vary greatly. The

SOC pool is dependent on the quality and quantity of organic matter, diversity, and population of microorganisms, the rate of decomposition, humification and formation of soil microaggregates and macroaggregates, all highly influenced by agricultural management practices.

2.7 Practices that promote carbon dioxide emission in agricultural soils

Over the past 200 years, humans have introduced 400 petagrams of carbon (PgC) to the atmosphere (Field & Raupach, 2004:18) in the process dramatically altering the carbon cycle. As shown in figure 5, there is more carbon dioxide in the atmosphere today (384 ppm) than there was in the year 1000 (just below 280 ppm). The concentration of carbon dioxide in the atmosphere has risen from close to 280 parts per million (ppm) in 1800, initially very slowly, then progressively faster to a value of 367 ppm in 1999, echoing the increasing pace of global agricultural and industrial development (IPCC, 1995:4). The majority of the increase in atmospheric carbon dioxide (about 80 ppm) has occurred since the 1850s.

Figure 5: Atmospheric concentration of carbon dioxide 1000-2007



Source: URL: ***http://www.earth-policy.org/Indicators/CO2/2008_data.htm#fig7***

The increase in atmospheric carbon dioxide is attributed to two principal human activities, land use changes (1.6 +/- 1.0 Pg C yr^{-}) and fossil fuel combustion (5.5 Pg +/-0.5 Pg C yr^{-}). The annual increase due to these two activities is estimated at 3.3 +/-0.2 Pg C/yr (Lal *et al*, 1998:1). Most of the increase in atmospheric carbon during the past 150 years was caused by a combination of fossil fuel burning and the reduction in SOC pool (Magdoff & Weil, 2004:5). Historically soils have lost between 40 and 90 Pg carbon globally (Braimoh & Vlek, 2008:11). Important activities that reduce SOC and accentuate emission of greenhouse gases include deforestation and biomass burning, disturbance through tillage and cultivation, drainage and indiscriminate use of fertilizers and lime (Lal, 2001:5). Annual net release of carbon from agriculture due to fossil fuel use on farms and shifting patterns in cultivation has been estimated at 2.5×10^{15} g, or about 15 percent of current fossil fuel emission globally (Kimble *et al*, 2002:13).

Conventional agriculture has resulted in a considerable decline in SOM levels and associated loss of soil structure in many soils throughout the world (Abbott & Murphy, 2003:1). It is estimated that arable lands have lost about 40 percent of their carbon content in less than 50 years (Roose *et al*, 2006:6), consequently the SOC pool in agricultural soils is much lower than its potential capacity and thus has a carbon sink potential. The environmental costs of this include loss in biodiversity, the nitrification of ground waters, eutrofication of watercourses, increased incidence of soil compaction, massive soil erosion, loss of soil fertility and loss in agricultural land estimated at 2000Mha.

Declining SOM is related to soil degradation. Soil degradation is defined as "decline in soil quality by several degradation processes (Roose, *et al*, 2006:26). Principal processes of soil degradation include (1) loss in topsoil in rooting depth due to erosion, (2) depletion of SOC pool to cultivation and erosion, (3) reduction in plant available water capacity due to decline in soil structure and reduction in SOC pool, loss of essential macro and micronutrients (Sparks,2002:8). Table 2 shows different types of soil degradation.

Table 2: Type of Soil degradation

Type	**Degradation Process**
Physical	Breakdown of soil structure Crusting & surface sealing Compaction, surface & subsoil Reduction in water infiltration capacity Increase in runoff rate and amount inundation, Water logging & anaerobiosis Accelerated erosion by water and wind
Chemical	Leaching Acidification Elemental Imbalance with excess of Al, Mn, Fe Salination Alkalization Nutrient depletion Contamination
Biological	Depletion of soil organic carbon Decline in soil Biodiversity Increase in soil-borne pathogens

Source: (Lal et al, 2004:5)

In recent decades, the global rate of soil degradation has increased dramatically. More and more soil is lost every day. Worldwide soil is being lost at a rate 13 to 80 times faster than it is being formed (Pimentel, 1998a:3-5). The U.S. is losing cropland soil at an average rate 13 times the sustainability rate of soil (Pimentel, 2000:420). India is losing soil at 30 to 40 times its sustainability (Pimentel 2000:421) and the rate of soil loss in Africa has increased by a factor of 20 in the last 30 years. The annual soil loss in South Africa is 2.5 tons per hectare (OECD, 2006:49), an estimation of 300 - 400 million tonne. FAO estimates that 140 million ha of high quality soil, mostly in Africa and Asia, will be degraded by 2010, unless better methods of land management are adopted (Merrington, Redman, Winder & Parkinson, 2002:74). In a major report on the environment released in 2002, the UN Environmental Program concluded, "Land degradation continues to worsen, particularly in developing countries where the poor are forced onto marginal lands with fragile ecosystems and in areas where land is increasingly exploited to meet food and agricultural needs without adequate economic and political support to adopt appropriate agricultural practices" (UNEP, 2002:299). In farm systems, the soil is degraded by management practices that do not return carbon to soil and practices such as tillage, which disturbs and increases the rate of decomposition.

2.7.1 Soil erosion

Extremely high rates of soil erosion are being recorded globally. Areas most affected are South Asia, especially the Himalayas-Tibetan ecosystem, Central Asia, the Loss Plateau of China, sub-Saharan Africa and the Maghreb region of Northwest Africa, the Andean region of South America, the Dominican Republic and the Caribbean and the highland of Central America (Roose *et al*,2006:32). Over the past 40 to 50 years, the arable land has been lost due to soil erosion at a rate of 0.6 Mha per year in China and nearly one third of the world's arable land has been lost by erosion and continues to be lost at a rate of more than 10 Mha per year at a global scale (Lal, 2006:536).

Soil erosion is associated with a decline in SOC content. Soil erodibility increases with decreased SOC concentration, which results in reduction in structural stability, and decline in water infiltration capacity (Roose *et al*, 2006:326). A gradual reduction in SOM levels in the soil, especially in the intensively cultivated arable area, leaves the soil more prone to compaction and erosion (Lampkin, 2002:13).

2.7.2 Conventional Tillage

Tilling the soil is disruptive and can promote soil erosion, high moisture loss rates, degradation of soil structure and depletion of soil nutrients and carbon stocks. Tillage accelerates soil carbon dioxide emission by improving soil aeration, increasing soil and crop residue contact, and enhancing plant nutrient availability (Magdoff & Weil,1993:275), increasing exposure of SOC in inter-and intra-aggregate zones to microbes for rapid oxidation. Intensive tillage reportedly has caused between 30 to 50 percent decrease in SOC since many soils were brought into cultivation. Many studies have shown a large short-term pulse of carbon dioxide released immediately following tillage, which partially explains SOC loss from soils (Kimble *et al*, 2002:87). Micro and macro channels within the soil created by natural processes such as decay of roots and worm activity are also destroyed by tillage. Conventional tillage practices also encourage the removal of crop residues and thus discourage the return of carbon.

2.8 Sustainable agriculture and soil carbon sequestration

Research (Kimble *et al*, 2002:337; Canadell, Pataki, & Pitelka, 2007:227) suggest that carbon sequestration in agricultural soils may be a useful method to counteract historical carbon emissions from fossil fuel. Watson *et al.* (1996) estimated that 0.4–0.8 Pg C/yr could be sequestered in agricultural soils globally by adopting sustainable agricultural practices. This corresponds to 10 percent of the global anthropogenic production of carbon dioxide for the year 1990 [6 Pg C/yr] (Wigley & Schimel, 2000:16). The carbon input to agricultural soils from roots, residues and amendments usually ranges from 1-15 Mg/ha/year, maintaining surface soil organic carbon stock ranging from 5 to 50 Mg/ha and microbial biomass carbon stock ranging from 0.05 to 2.5 Mg/ha (Magdoff & Weill, 2004:24). The potential of soil carbon sequestration at different eco-regions are shown in table 4.

Table 3 : Technological options for carbon sequestration (ton/ha/yr) (UNEP,1997)

Technological options	**Temperate climate**		**Tropical and subtropical**	
	Humid	**Semi-arid**	**Humid**	**Semi-arid**
1. Conservation tillage	0.5-1.0	0.2-0.5	0.2-0.5	0.1-0.2
2. Mulch farming(4-6 Mg/ha/yr)	0.2-0.5	0.1-0.3	0.1-0.3	0.05-0.1
3. Compost (20 Mg/ha/yr)	0.5-1.0	0.2-0.5	0.2-0.5	0.1-0.2
4. Elimination of bare fallow	0.2-0.4	0.1-0.2	0.1-0.2	0.05-0.1
5. Integrated Nutrient Management	0.2-0.4	0.1-0.2	0.2-0.4	0.1-0.2

6. Restoration of eroded soils	-	0.1-0.2	-	0.05-0.1
7. Restoration of salt affected soils	0.05-0.10	0.05-0.10	0.2-0.4	0.1-0.2
8. Agricultural intensity	0.05-0.10	0.05-0.1	0.2-0.5	0.1-0.3
9. Water conservation and management	0.05-0.10	0.1-0.3	0.01-0.1	0.1-0.3
10. Afforestation	0.2-0.5	0.1-0.3	0.2-0.5	0.05-0.10
11. Secondary carbonates	-	0-0.2	-	0-0.2
12. Improved pasture management	0.2-0.5	0.1-0.3	0.1-0.2	0.05-0.1

Source: International fund for Agricultural development, 51:1999

Management for soil carbon sequestration include practices that conform to principles of sustainable agriculture (e.g. erosion control, diverse cropping improve soil fertility) (Lal *et al*, 2001:553). Sustainable agricultural practices influence carbon inputs mainly in the following ways: (1) increasing primary production (e.g. perennial crops, plant nutrition and organic amendments); (2) increasing the proportion of primary production returned to or retained by the soil (crop residue and placement) and (3) influencing both microbe and plant induced changes in the soil structure that can suppress the rate of decomposition through enhancing soil aggregation (Rees, Ball & Watson,2001:16).

2.8.1 Sustainable Agriculture

Sustainable agriculture is defined as "one that over the long-term enhances environmental quality and the resource base on which agriculture depends, provides for basic human food and fibre needs, is economically viable and enhances the quality of life for farmers and society as a whole" (Olson,1992:54). Sustainable agriculture encompasses farming practices that indefinitely produces high quality food, preserve and enhances natural resources, environmental safe and contribute to the well being of the entire social fabric.

For an agricultural production system to be sustainable in the long-term, the following conditions must be satisfied:

i) Soil resources must not be degraded in quality through soil structure (i.e., compaction, loss of SOC) or through the build-up of salts, selenium, or other toxic elements; nor can topsoil depth be significantly reduced through erosion, thereby reducing water-holding capacity.
ii) The biological and ecological integrity of the system must be preserved through management of plant and animal genetic resources, crop pests, nutrient cycles and animal health. The development of resistance to pesticides must be avoided (Edwards *et al*, 1990:68).

2.8.2 Sustainability in agriculture

As it pertains to agriculture, sustainability describes farming systems that will be productive not only today but through generations. It entails preserving the overall balance and value of natural resources of all living and nonliving organisms. It suggests permanence in food production systems in a socially responsible, ecologically sound, and economically viable way. Thus, agricultural sustainability is defined as the ability to maintain productivity, whether of a field or farm or nation in the face of stress or shock. A stress may be increasing in salinity, erosion, or debt; each is a frequent, sometimes continuous, relatively small predictable force having a large cumulative effect (Conway & Barbier, 1990:37). For agricultural sustainability to be achieved, three important criteria must be met: that is environmental quality and ecological soundness, plant and animal productivity and socio-economic viability (Smith & McDonald, 1998:18). According to FAO (1996), information in an integrated manner from the economic, environmental, and social dimensions are sure indicators of agriculture sustainability.

Systems high in sustainability are making the best use of natures good and services whilst not damaging these assets. The key principles are to:

i) Integrate natural resources such as nutrient cycling, nitrogen fixation, soil regeneration and natural enemies of pest into food production processes

ii) Minimize the use of non-renewable resources that damage the environment and harm the health of farmers and consumers

iii) Make productive use of the knowledge and skills of farmers, improving their self-reliance

iv) Make productive use of people's capacities to work together to solve common agricultural and natural resources problems such as pests, watershed, irrigation, forest and credit management (Hester & Harrison, 2005:2).

2.9 Sustainable agricultural practices that promote soil carbon sequestration

Sustainable agriculture does not prescribe a concretely defined set of technologies practices or policies (Pretty, 1995:1248). It is a practice of various techniques and principles ranging from IPM (Integrated Pest Management) to permculture, to agroecological systems (Jhamtani, 2007:8). Thus in sustainable agriculture there is no single approach that can be applied all over the world in a uniform manner. Different techniques and systems are applied, and adapted, in different ecological and socio-cultural systems (Olson, 1992:54). Accordingly, the rate of soil carbon sequestration through the adoption of sustainable agricultural practices also differs among eco-regions and is dependent on soil texture and structure, rainfall, temperature, farming systems and soil management (Lal, 2004:1623).

It is generally known that astute management of organic matter is the key to sustainable agriculture (Stevenson & Cole, 1999:78). Sustainable agricultural practices that promote soil carbon sequestration through management of organic matter are discussed below.

2.9.1 Organic amendments

Organic amendment covers a wide range of inputs, from animal manure to solid wastes, various composts and especially grown cover crops, often legumes, which are ploughed in as green manure (Callow, 1997:11). The main advantage of organic amendments is that they are rich in labile carbon fractions, which are the source of energy for microorganism. Organic amendments are known to reduce the activity and/or survival of soil pathogens such as *Pytophthara cinnamomi* and *Sclerotium rofsii* (Rechcigl, 1995:17). Organic amendments improve the soil quality by reducing compaction and crusting and promoting drainage and water holding capacity.

2.9.2 Conservation tillage

Conservation tillage- reduced-till, no-till, strip tillage, and chisel tillage are sustainable management practices that increase the SOC by leaving the soil relatively undisturbed. Conservation tillage is probably the best known conservation practice, evolving from practices that range from reducing the number of trips over field to raising crops without primary or secondary tillage and maintaining an effective amount of residue on the soil surface (Reeder, 2000:6). Root residues have some advantages over top residues as carbon sources. They are intimately mixed with soil at all times and, as they decompose, the microbial gums produced are well distributed and hence in a position to act as cements between soil particles to promote aggregation. Top residues also constitute sources of gums but these are not distributed as effectively in the soil (Allison, 1973:421). The method of addition of plant residues to soil affects the rate of decomposition and build-up of organic matter reserves. When left on the surface as mulch residues often become desiccated and decompose more slowly than if incorporated (Schnitzer & Khan, 1978:195). The crop species used, and the sequence of these crops in rotation can affect the quantity and quality of residues, and thus the quality of SOM.

2.9.3 Surface mulch

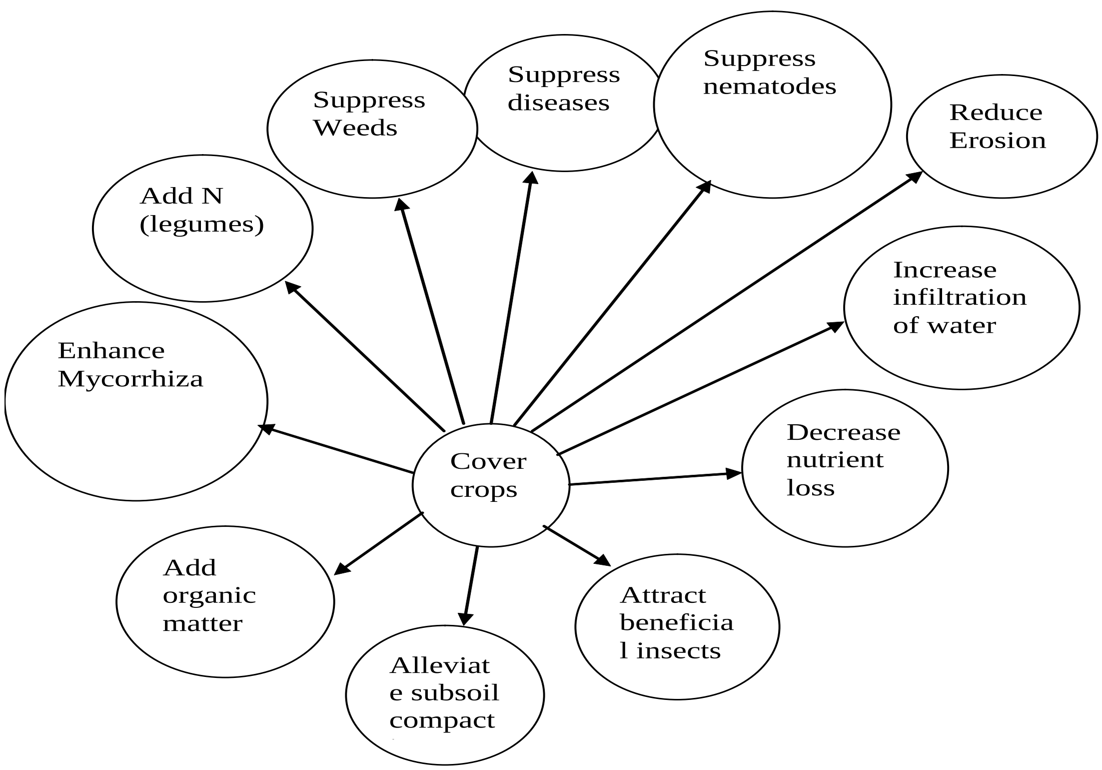
The term mulch as used here refers to any naturally-formed, undisturbed soil covering; any material added to serve as soil cover; and to crop residues left on the surface as dead or dying material (Allison, 1974:500). Mulch may be classified as either organic or inorganic. Organic mulches include hay, straw, compost, carpet and under felt. Inorganic mulches include stones, plastic sheeting, and plastic weed mats (Mason, 2003:46). Organic matter on the soil surface is much more effective at moderating soil temperature than plastic mulch. As typically, installed plastic mulch covers only 50 to 75 percent of the soil surface, causing runoff water to concentrate on the soil areas exposed in crop inter-rows (Magdoff and Weil, 2004:16-18). Mulches are used for increasing water infiltration, reducing soil drifting, reducing evaporation, modifying soil temperature, controlling weeds, and increasing yield. They also increase biological activity, modify the level of available nutrients and maintain or increase the organic matter level (Schnitzer & Khan, 1978:200).

2.9.4 Green manure / Cover crops/ living mulch

This practice of turning into the soil undecomposed green plants tissues is referred to as green manuring (Brady, 1974:546). Green manure, often called cover crops are plants that are used for incorporation into the soil to build SOM. Cover crops can have significant positive effect on soil health and are an important tool for SOM management. The use of cover crops usually leads to better nutrient use, more available nitrogen (especially if a legume is grown), better water infiltration, and better soil aggregation. Cover crops can also have important pest management implications (Magdoff and Weil, 2004:61). Some of the advantages of cover crops are illustrated in Figure 6. Incorporation of cover crops into the soil as green manure accelerates the activities of soil microorganisms and the formation of soil aggregates (Akinyemi, 2007:49). Cover crops retain and recycle plant nutrients (especially nitrogen) between crops, provide habitat for beneficial microorganisms and increase plant diversity.

A major benefit is the avoidance of NO^-_3 leaching in susceptible soils, because NO^-_3 is taken up by the green manure crop and slowly released to a subsequent cash crop as the residues decompose (White, 2006:236). When green manures are incorporated into the soil and have been thoroughly decomposed there is an improvement in tilth of the finer-textured soils. This is brought about by the interplay of a number of factors that result in improved aggregation of the fine clay particles and in a lower bulk density (Allison, 1973:456).

Figure 6: Potential effects of using cover crops



Source :(Magdoff and Weil, 2004:59)

Cover crops are mainly leafy type of crops high in nutrients and non-humic substances. They include annual, biennial, or perennial herbaceous plants including annual grasses, forbs, and legumes. Piper and Pieters classify leguminous green manure crops as: (1) summer annuals, chiefly soybeans, peanuts, beans, velvet beans, common vetch and field peas; (2) winter annuals, including hairy vetch, common vetch, crimson clover, bur clover, field peas and red clover (3) biennials or perennials comprising of red clover, alsike clover, white clover, alfalfa and sweet clover (Allison, 1973:457).

2.9.5 Green manuring and under sowing

Under sowing involves growing a green manure crop at the same time as a crop among the crop plants. Sometimes these are sown with the crop or slightly later when the crops are already growing. This reduces competition between the green manure and the crop. An under sown crop is usually very beneficial, and its occasional harmful effects can be circumvented by good management. Its beneficial effects include nitrogen fixation, humus formation, improving the soil physical conditions, conservation of nutrients, control of erosion, and control of plant diseases (Schnitzer & Khan, 1978:193).

2.9.6 Crop rotation

Crop rotations and biological diversity have long been cornerstones of successful, traditional agriculture production systems (Edwards, 1990:107). Crop rotation consists of growing different crops in succession in the same field, as opposed to continually growing the same crop. Growing the same crop year after year guarantees pests food supply-and so pest population increases. It can also lead to depletion of certain nutrients (Mason, 2003:16). The aim of rotation is threefold: to balance nutrient demands, foil insects and disease attacks, and deter weeds. Its benefits include maintenance of soil structure and organic matter, and reduction in soil erosion that is often associated with continuous row cropping (Janvier, Villeneuve, Alabouvette, Edel-Hermann, Mateille and Steinberg, 2006:2). In addition, rotations influence soil biology and reduce problems with many plant pests (Magdoff and Weil, 2004:49) and weeds (Lampkins, 2003:129).

Different types of crop rotation

In intercropping systems, there is some degree of overlap among crops so that crops are diversified both in time and space. Intercropping has logical advantages. Among the benefits is that it results 'in more efficient utilization of resources (light, water, nutrients) by plants of different height, canopy structure and nutrient requirements; provides insurance against crop failure, especially in areas subject to frosts, floods and droughts; provides effective cover to soil and reduces the loss of soil moisture (Madeley,2002:27; Prasad & Power, 1997:341). Intercropped systems are more efficient in recycling nutrients and reducing nutrients loss through leaching than conventional systems. Legumes are an important component of multi cropping systems as they fix nitrogen into the soil.

Intercropped systems include mixed intercropping, where two or more crops are grown without a distinct row arrangement; **row intercropping**, where at least one crop is planted in a row; **strip intercropping**, where at least two or one crops are planted in strips wide enough to allow for independent cultivation but narrow enough to interact with one another ecologically. The hypothesis is that the interactions (physical, biological, ecological, management) between components of a system with greater spatial diversity will enhance biomass yield and resource use while decreasing the emissions of greenhouse gasses and nitrates and the incidence of pests and diseases compared to sole cropping of the same species (Dent,2000:250). **Relay intercropping** is where a second crop is planted into a first crop before the harvest so that there is some overlap in the life cycles of the two crops (Edward *et al*, 1990:124). When arable crops are grown as intercrops in alleys between tree rows, the term generally used is alley cropping. **Mixed cropping** is a practice in arid regions of the world where the seeds of a number of crops such as pearl millet, mung-bean, and moth bean are mixed together and sown together at the onset of rains. This practice assures the growth of at least one of these crops, regardless of the weather that follows (Prasad & Power, 1997:341).

2.9.7 Sustainable management of weeds

Well managed weeds are an important component of sustainable agriculture. The National Standards for organic production in Australia listed the following practices for weed control: choice of appropriate species and varieties; biological controls, such as crop rotations, biodynamic measures, tillage, mulching, mowing, and grazing (Akinyemi, 2007:101). Certain weeds (mostly *Umbelliferae, Leguminosae* and *Compositae*) play an important ecological role by harboring and supporting a complex of beneficial arthropods that aid in suppressing pest populations (Altieri, 1999:24).

2.9.8 Farm Yard Manure

For centuries, farm manure has been the most important agricultural by-product. Its use has long been synonymous with a successful and stable agriculture. It supplies organic matter and plant nutrients to soil (Brady, 1974:534). Manure is often presumed to result in higher increases in SOM because it consists of relatively recalcitrant compounds. The most easily oxidized compounds is the original plant tissues having been broken down by the animal digestive system before excretion of the manure (Magdoff & Weil, 2004:52)

Manure is a combination of faeces, urine, bedding (litter) and feed wastage of animals which are valuable sources of both macro and micronutrients. The components are partially degraded plant material with cellulose, starches and sugars, hemicellulose, and lignin lingo-protein. Moreover, manure contains all the essential plant macro-nutrients, N, P, and K. Other forms of organic matter additions have been observed to result in similar win-win situations. For example adding a moderate amount of manure to soil can actually reduce the P losses in runoffs, even though the manure itself carries significant quantities of P (Magdoff & Weil, 2004:17). Feeds contain certain nutrients, some of which are recovered in the manure. How much is recoverable depends on the quality and amount of feed, the age and the kind of animal (Schnitzer & Khan, 1978:191). One other important organic component of animal manure is the live component, the microorganisms. Especially in ruminant animals (for example, cattle, and sheep), the manure is teeming with bacteria and other microorganisms. Between one fourth and one, half of the faecal matter of ruminants consists of microorganism’s tissues (Brady, 1974:539). All animal manures are useful as fertilizer. When mixed into composed as part of the composting process, the final material provides excellent all purpose fertilizer (Mason, 2003:40). Salter & Schollenberger (1939) concluded that generalized values for the recovery of fertilizer constituents in the excrement are as follows: nitrogen, 75%; phosphoric acid, 80% and potash, 85% (Allison, 1973:422).

Table 4: Composition of selected Animal manure (dry-weight basis)

Constituent	**Beef/Dairy (%)**	**Poultry (%)**	**Swine (%)**	**Sheep (%)**
Nitrogen (N)	2-8	5-8	3-5	3-5
Phosphorus (P)	0.2-1.0	1-2	0.5-1.0	0.4-0.8
Potassium (K)	1-3	1-2	1.0-2.0	2.0-3.0
Magnesium (Mg)	1.0-1.5	2-3	0.08	0.2
Sodium (Na)	1-3	1-2	0.05	0.05
Total soluble salts	6-15	2-5	1-2	1-2

Source: Prasad & Power, 1997: 328 citing Miller and Donahue. 1992: 196-211.

2.9.9 Composting

Composting is a technique of similar long standing that combines the use of animal manure, green material, and household waste (Pretty et al, 1996:133). It is a microbiological conversion of biodegradable organic waste to stable humus by indigenous micro-flora, including bacteria, fungi, and actinomycetes, which are widely distributed in nature. Diverse composting processes have been developed all over the world. They can be broadly classified into aerobic and anaerobic composting processes.

The major objectives in composting are to stabilize putrescible organic matter, to conserve as much of the plant nutrient and organic matter as possible, and to produce uniform, relatively dry product suitable for application (Prasad & Power, 1997: 328). Any organic material, if left long enough will eventually rot down due to the action of microorganisms and when it is incorporated into the soil it will improve the physical and chemical features of the soil. This improvement, like most other sustainable practices, will not occur immediately (Mason, 2003:42). Amending soil with composted organic wastes is often an effective means of increasing SOC. Because the most labile carbon fractions are lost during the composting process, much of the carbon in the final compost as applied to the soil is more recalcitrant than in the uncomposed material (Magdoff and Weil, 2004:52).

Composting is a practical means for storing organic residues and stabilizing nitrogen for later use as a soil fertility amendment (Magdoff & Weil, 2004:20) but the big disadvantage of composting is the loss of nitrogen during the process and the low plant availability of the remaining nitrogen (Edwards, 1990:94).

2.9.10 Vermicomposting/Earthworm composting

Vermicomposting is a method of making compost with the use of earthworms e.g. *Eisenia fetida*, which generally live in soil, eat biomass and excrete it in digested form. This compost is generally called vermicompost or worming-compost. It’s estimated that 1800 worms, which is an ideal population for one square meter, can feed on 80 tonnes of humus per year (NIIR Board, 2004:8). Earthworms can consume practically all kinds of organic wastes, consume two to five times their body weight and after using five to ten percent of the feed stock for growth, excrete mucus coated undigested matter as nutrients and vitamins rich worm casts. Vermicasts are resources that are rich in mineral nutrients, vitamins, plant growth hormones, proteins and enzymes. Thus, vermicast is considered as a very good organic fertilizer and soil conditioner.

Vermicompost is rich in plant nutrients. It provides vital macro elements such as N, P, K, Ca, Mg and micro elements such as Fe, Zn, Cu, etc. Apart from this, it contains plant growth-promoting substances such as cytokinins, and gibberalins. It also harbours beneficial micro-flora. Worms also have the capacity to store heavy metals and pesticides in their tissues. Thus, to a certain extent, they play a role in detoxifying polluted soils, too.

2.9.11 Nutrient management

The key to sustainable agriculture is nutrient cycling (Edward, 1990:105). When crops are harvested, nutrients are invariably removed and so have to be replaced. There are a variety of nutrient sources including the mobilization of existing nutrients in the soil and parent rocks; the fixing of nitrogen from the atmosphere; or the supply of organic or inorganic fertilizer (Pretty *et al*, 1996:132). Nutrient management involves the balanced supply of nutrients to improve the productivity, stability, and sustainability of the production system.

There is a wide variety of organic sources of nutrients, including plant residues, farmyard manure, livestock waste, and green manure from leguminous crops, biogas, slurry, municipal sewage sludge, and biological nitrogen fixers (Raman, 2006:316). Organic manures have more merits because they do not impact on soil microbes but help improve soil fertility and environmental quality.

It is clear that soil carbon sequestration maybe significant and may be influenced through the use of particular farming practices (OECD, 2001:90). Sustainable agriculture is beyond doubt a viable solution that could significantly help in reducing greenhouse gas levels into the atmosphere by promoting soil carbon sequestration and soil quality.

2.10 Conclusion

Scientific evidence has shown that world emission of carbon dioxide have increased at a great pace, posing threat to the global system. It is evident that if the emissions remain unabated, the concentration of CO_2 may more than double by the end of the 21st century. Adoption of sustainable agricultural practices promotes soil carbon sequestration. The amount of SOC is determined by the balance between the rates of organic carbon input and output. Practices that promote soil carbon sequestration are reduced tillage, erosion control, diversified cropping system, balanced fertilization, mulching, and applications of organic material such as manure. Reducing emissions from agricultural activities involve reducing erosion and avoiding tillage, which disturbs the soil and accelerates decomposition and microbial respiration. SOC has profound influence on soil properties and processes and it is the most important indicator of soil quality. Soil quality is defined as the ability of the soil to perform ecological functions while maintaining the integrity of natural resources.

CHAPTER 3: AN INVESTIGATION INTO THE ADOPTION OF SUSTAINABLE FARMING METHODS AND THEIR IMPACT IN THE YAVATMAL DISTRICT OF INDIA

3.1 Introduction

This case study is an investigation into sustainable farming techniques adopted by Indian farmers and the impact that these have. The study relies on primary data collected from 5 farms located in Shiroli and Chincholi villages in the Ghantanjee block of Yavatmal district of Maharashtra. The study compares four farms that are managed under sustainable farming techniques with a farm managed under conventional agricultural practices and compares the SOC levels between the different farms.

The objective of the study

The objectives of this study were to establish (1) how Indian farmers have adopted sustainable farming practices to overcome agricultural challenges, and (2) what SOC contents are, across different farm systems.

The study focused on answering the following critical questions:

1. How have farmers in the Dharamitra program responded to challenges to their agricultural production?
    a. What are the challenges and what has brought them about?

b. What has motivated them to change management practices and adopt sustainable farming methods?
c. What methods have been adopted?
d. What lessons can be learned from the adoption of sustainable farming techniques?

2. What are the SOC contents across different farms?

3.2 Background

The sustainable agriculture paradigm is gaining great momentum all over India and it has one ultimate goal that is to meet the three key objectives of sustainable development - social development, environmental protection and economic advancement and security (Sustainet, 2006:6). The quest and challenge of sustainable agriculture as established from interviews with farmers in India and Dharamitra staff is to create a production system that is:

- Less dependent on energy intensive inputs,
- Less expensive but with adequate returns
- A system that remains productive while maintaining the integrity of natural resources,
- In addition, a system that safely produces enough high quality healthy food to meet the nutrition needs of the growing population.

3.3 Sources of challenges in Indian agriculture

By using traditional knowledge and pre 1960s innovative methods of farming, developed and practiced over generations, sustainable agriculture aims to regenerate the dysfunctional agricultural production system (FAO, 1997). This is achieved by discarding the entrenched culture of high-tech monoculture and chemical practices and reintroduce indigenous knowledge well supplemented with modern researched ideas into the system of farming (Hansran, Permal & Chandrakandan, 2001:67). It is hoped that this will give rise to a sustainable production system that will bring long lasting solutions to the intricate problems within the Indian agriculture (Kumar, 2002:4). These problems can be traced back to 1947 after independence when India faced two major economic challenges: achieving food security and alleviating poverty (Mahadevan, Tuan & Yu, 1994:304). In a country that relies predominantly on agriculture, the logical choice was to promote growth in agriculture to meet both of these challenges. Several agricultural reform programmes were launched. These programmes included

- extending frontiers of cultivation,
- increasing productivity through technology
- Intensifying input use with irrigation and other inputs.

However, the agricultural reform programmes were not entirely successful and as a result, many people remained hungry. Efforts to eradicate poverty and achieve food security necessitated the inception of the green revolution (Hansran *et al*, 2001:66). This is the use of agricultural technology characterized by new fast growing varieties of grain crops, which had high yields, energy intensive mechanisation, high dependency on synthetic chemical inputs such as pesticides and fertilizers, and less crop diversification. In the process, the known and trusted traditional methods of farming such as mixed cropping and crop rotation were gradually replaced, and also most traditional grain varieties became extinct and those that were newly introduced were continuously being replaced by other new varieties.

Admittedly, the technology did much to raise rural and urban food and fibre production, establishing India as the world's biggest agricultural producer and exporter. Between 1978 and 1979, a grain output of 131 million tonnes was recorded. No other country in the world, attempting the Green Revolution recorded such levels of success (Desai & Pujari, Undated: 101). The production of wheat, which stood at 11 million tonnes in 1960-1961, increased to about 35 million tonnes in 1978-1979 i.e. an increase of 218 percent in total wheat production (Mchead, 2002:154). Part of this increase can be attributed to an extension of the area under cultivation, but the yield per acre rose from 851 kg to 1.570 kg per hectare, signifying an increase of about 84 percent. Increase in production of maize during 1960-1961 and 1978-1979 is estimated at 52 percent. Rice production rose from 35 million tonnes in 1960-1961 to 42 million tonnes in 1970-1971, and further to 54 million tonnes in 1970 -1979. The yield per hectare also recorded an improvement from 1,013 kg in 1960-1961 to 1.339 kg in 1978-1979, which culminated in a record achievement of 108 million tonnes of food grain in 1970-1971 (Kumar, 2002:203-204). While the green revolution in India had positive repercussion in term of general self-sufficiency in food production, it brought with it the much larger problems of environmental degradation and unequal distribution of wealth (Ramakrishna, 1992:1).

3.4 Consequences of the green revolution in India

3.4.1 Environmental Problems

Deforestation, deterioration of soil health, increased soil salinity, the problem of water-logging, gradual depletion of ground-water, environmental degradation, residual toxic effects of pesticides, destruction of many beneficial organisms and contamination of food chain were the glory downstream consequences of intensive agriculture (Hansran *et al*,2001:66). Green Revolution practices destroy soil quality over the long-term through a variety of mechanisms including erosion, increased soil salinity through irrigation, and a decreased flux of organic material to the soil (Desai & Pujari, 2007:104). It has been estimated that about 12 billion tonnes of soil is eroded annually (Hansran, *et al*, 2001:41). It is estimated that of the country's total geographical area of nearly 329 million ha, about 188 million ha, (57 percent) is degraded through various mechanism such as wind and water erosion, water-logging, salinity, and desertification. In 1947, the area of soil degradation was about 110 million ha (Desai & Pujari, 2007:109). In addition, the excessive use of pesticides, herbicides and other chemical inputs not only killed targeted species but also non-targeted ones including humans. The widespread destructive use of these chemicals induced resistance in pest. A 1,200 percent increase of pests has been experienced as a result of applying pesticides (Shiva, 2000: 4). This has disrupted the balance in the natural ecosystem and the natural biodiversity.

3.4.2 Socio-Economic Problems

To maintain high productivity poor, marginal farmers had to dig deep into their pockets to purchase artificial production inputs of seeds and fertilizers. These not only increased yields, but had the consequence of degrading the soil. For farmers to remain productive, it required greater expenditure and more application of external inputs. This system however could not be sustained. As a result, farmers were pushed into debt, as they were sucked into the global market for costly seeds and chemicals (Shiva, 2005:95). This resulted into destitution and suicide. This trend was predominantly noticed in small farmers who did not have capital to purchase seeds, fertilizers and pesticides since the nationalized financial institutions did not have adequate systems for providing loans to small farmers. The majority of farmers resorted to banks and private exploitative moneylenders for loans that often carried exorbitant interest rates. By so doing, many were thrown further into the deep well of poverty and debt (Quital, undated: 68). Only wealthy farmers, landlords, and morally unprincipled chemical companies profited.

Farmer suicide in Yavatmal District

The suicide epidemic is said to have its epicentre in Yavatmal district of Maharashtra. The National Crime Record Bureau (NCRB) reported 640, 819, 832, 787 and 786 suicide cases for the years 2000 to 2004. In 2007, 1,593 farmers committed suicide in that region. According to a study by YASHADA (2006), farmers in this region commit suicide mainly because of two reasons - firstly because they are unable to generate funds from their farms to pay off various loans and secondly because of the absence of a person, group or institution to whom to turn in order to seek reliable advice, whether for agricultural operation, for seeking funds or for handling private and personal issues. The study further concluded that farmers take loans to buy production inputs and because of crop failure they fail to pay back their loans and in despair, they commit suicide often with the very same pesticide they use in their fields.

To tackle the situation many NGOs and government organizations in India have developed special programs that promote the adoption and diffusion of sustainable agriculture. The programs aim to demonstrate increased sustainability compared to chemical farming, and to reveal the holistic benefits that can be accrued simply by farming with on-farm and local resources instead of chemicals.

3.5 The NGO Dharamitra

Dharamitra is one of the organizations that encourage interested farmers to convert to sustainable agriculture. The program supported by SWISS AID (India) was implemented in collaboration with seven grass root level NGOs and is under aegis of CAPART, New Delhi. The organization supports farmers to make optimum use of locally available resources and reduce dependency on chemical inputs that have left them in a spiral of debt. Under the project, which started in 2003, the number of farmers covered increased from 165 in 2002-2003 to 715 in 2006-2007. The total holding of these farmers is 5436.70 acres.

Dharamitra is currently working in 19 villages that are grouped into four clusters- Shiroli, Rampur, Lingi and Mandwa. Falling under each cluster are four to five villages. In each village, farmers are organized into groups known as *'Farmers' Study Groups* (FSGs). The FSGs serve as a platform for farmers to learn and share innovative ideas of farming. Assigned to each group is a well trained female or male motivator. The foremost task of motivators is to establish contact with farmers in the village, collect field data and report findings to the organization. The motivator meets with farmers on a regular basis to discuss problems they are facing and to give advice. Apart from the special training offered by Dharamitra, motivators are selected based on their farming experience, which enables them to deal with the daily problems faced by farmers. The progress of farmers is monitored on a regular basis by the motivator who visits the fields to check if farmers are still coping with the sustainable agricultural techniques. These personal visits create the opportunity for the motivator to have a one on one interaction with farmers, allowing them to share deep personal problems they cannot share in the presence of other farmers.

From time to time Dharamitra organizes exposure tours to successful farmers who are farming sustainably. In these tours newly converted farmers, those with prospects of converting and those who are sceptical about sustainable agriculture see and experience the full benefits of sustainable farming through other farmer's successful stories and experiences. Seeing is believing, and through seeing many poor discouraged farmers learn that they can use on-farm inputs to produce food for domestic consumption and for the market at very low costs in the process enabling them to generate sufficient profit to pay off their debt. Through these tours, farmers learn the ability to attain self-sufficiency, freedom from debt and a chance to live a healthy fulfilled life.

Dharamitra run the following specific programs:

Community seeds and grain banks: The community seed and grain banks are helping local communities to reintroduce varieties of grains and seeds lost during the era of the Green Revolution. In addition, traditional methodologies of storing grains and seed are recalled with the help of older local women who are happy to share their knowledge with the young women in the village.

Community kitchen gardens: Many families are part of Dharamitra's kitchen garden program. The families use traditional farm practices to produce food for domestic consumption. Through these kitchen-gardens, families are able to generate additional income by selling excess food to the market.

3.5.1 Sustainable farming techniques advocated by Dharamitra

The Dharamitra program teaches farmers naturally-based techniques. To date with the aid of local farmers Dharamitra have formulated seventeen low-cost sustainable agricultural techniques. Applications of these techniques are aimed at improving soil quality and enhance crop production. The acceptance levels of these techniques range between 36 and 74 percent. The details of the levels of adoption of various techniques are given in table 6.

Table 5: Level of Adoption of various sustainable agriculture techniques by farmers

	Techniques	**No of farmers who adopted**	**Acceptance levels**

		techniques	techniques (%)
1	Contour bunding.	270	36
2	Agro-waste utilization for incorporation in the farm or composting.	513	71
3	In situ composting of weeds.	565	75
4	Sowing across the slope.	432	58
5	Seed germination test.	423	56
6	Seed treatment (using cattle dung + urine +ant hill soil.	352	47
7	Preparation and use of compost and vermin-compost.	482	64
8	Mixed cropping patterns.	502	67
9	Adoption of gap filling management.	304	40
10	Deep hoeing.	492	66
11	Use of Sanjeevak[1].	108	14
12	Use of vermiwash.	29	4
13	Use of cattle urine and Neem spray.	268	36
14	Use of trap crops.	168	22
15	Use of bird perches.	318	42
16	Tree planting on farm bunds.	205	27
17	Establishment of farm ponds.	16	2
	Total number of farmers studied	**751**	

Source: Ray of Hope, Dharamitra.

As shown in table 6, the in-situ composting of farm weeds and use of agro-waste for incorporation into the soil have been the most popular techniques. Before these were introduced, farmers used to pick up weeds after weeding operations and dump the debris on farm bunds. Similarly, farmers used to burn agro-waste left over after post harvest clearing of land. Because of education and training farmers collect weeds and incorporate agro-waste in their farms as sources of organic matter and nutrients. Farmers understand that the correct use and application of these techniques improves soil organic content, soil quality and nutrient availability. Crop

[1] A fermented liquid manure prepared from cattle dung and cow urine

rotation and multiple cropping systems increase the diversity, quality and quantity of crop residues produced. Mixed-crop and livestock systems optimize the agro-system by increasing organic matter accumulation. Cattle dung, urine and Farm Yard Manure (FYM) are an excellent source of soil and plant nutrients.

3.6 Study Area

For the purpose of this study, five farm systems were selected from Shiroli and Chincholi village in the Ghantanjee block of Yavatmal district of Maharashtra. Yavatmal district is located in the eastern region of the Maharashtra state of India, between 19º26 to 20º42 North latitudes and 77º18 to 79º98 East longitudes.

Figure 7: Map of study area Yavatmal (Maharashtra)

www.mapsofindia.com/.../maharashtra/yavatmal.htm

Yavatmal is well known as “the land of farmers”. There are 1 004 256 hectares under cultivation and 77 309 hectares that are non-cultivated. Most of the cultivated land in the area ranges from flat plains to undulating slopes. Soils are shallow to medium depth, light to medium textured, black to grey, with extremely low levels of humus and therefore low productivity. Soils, particularly on the slopes are degraded due to erosion (State Development Report series, 2007:141). Agro-climatically, the region forms part of the Decca Plateau, which is a hot semi-arid eco-region.

Yavatmal's agriculture is limited by unavailability of water in most of the district (Narayanmoorth & Deshpande, 2005:84). In the absence of facilities for irrigation, these lands are farmed under rain-fed conditions. Major crops grown in Yavatmal district are cotton (*Kapoos*), sorghum (*Jowar*) toor (*Yellow beans*), wheat (*Gahu*), Sugarcane *(Oos*), groundnut (*Bhooimung*) and chillies (*Mirchi*) (Sirsikar, 1995:72).

3.7 Methodology

3.7.1 Data collection through interviews with farmers

Data was collected from farmers through structured interviews, observation, and discussion. The survey was conducted during the month of February for three weeks in 2008. Participating farmers were selected by Dharamitra. In total, eleven farmers were interviewed. A set of predefined questions in a form of a questionnaire were asked in the same order for all respondents, to allow data comparability. The interviewer personally recorded the response on the form. This approach is advantageous because it accommodates respondents who have low level of literacy. Data is validated while being collected, and this helps overcome misinterpretation of questions and answers. Questions that were asked in the questionnaires were mainly of explanatory nature and farmers were asked questions that required them to reply at length. The questionnaire is included in Appendix 1.

3.7.2 Data collected through interviews with Dharamitra staff members

Open-ended questions about the organization, the research work already done and progress achieved were asked in the interview. In addition, the accuracy of the information collected during interviews with farmers was confirmed in these interviews.

3.8 Soil sampling

Composite soil samples, each made up of fifteen sub-samples were collected from farm plots following a zigzag sampling plan. Twelve composite soil samples[2], three per field were collected from four organic farms and three were collected from a farm managed under conventional farming practices. Samples were collected from 0 to 15 cm depth using a spade and placed in a plastic bucket. Sub-sampling spots were at regular distances from each other with the aim of covering the whole sample area.

[2] Relevant information regarding slope, drainage, irrigation, previous cropping history, fertilizer used for crops were provided with each sample

3.9 Soil preparation

Each soil sample was divided into four equal parts, from which two diagonal parts were removed and the remaining two parts retained. This process was repeated until the successive quarter was reduced to a weight of less than 50 g (see figure 8).

Figure 8: Collected soil sample divided into four equal parts

The air dry soil was passed through a 2-mm sieve for analysis. Before sieving, the soil clods were lightly crushed in wooden mortar and pestle. Plants residues, gravels and other foreign matter retained on the sieve were discarded. A representative sub-sample was grind and sieved through a 0.5-mm (32-mesh) sieve. Soil samples were transferred into a plastic bag and labelled showing the farmer's name and date of collection.

Figure 9: Soil samples in labelled plastic bags

3.10 Soil analysis

Samples were analyzed for organic carbon at the Dharamitra laboratory. The Walkley-Black method was used to determine the organic carbon content and the procedure is detailed below:

The SOC, which contains about 48 to 58 percent organic carbon, is oxidized by chromic acid utilizing the heat of dilution of sulphuric acid. The unutilized chromic acid is determined by back titration with standard ferrous ammonium sulphate solution using diphenyamine/ferroin as an indicator.

Reactions

During Digestion

1) $2K_2Cr_2O_7 + 8H_2SO_4 = 2K_2SO_4 + 2Cr_2(SO_4)_3 + 8\ H_2O + 6(O)$

2) $3C + 6(O) = 3CO_2$

During titration

3) $K_2Cr_2O_7 + 7H_2SO_4 + 6FeSO_4 = K_2SO_4 + Cr(SO_4)_3 + 3Fe_2(SO_4)_3 + 7H_2O$

Two molecules of $K_2Cr_2O_7$ give out 6 atoms of nascent oxygen in presence of H_2SO_4. Reaction indicates that the six atoms of nascent oxygen released from two molecules of $K_2Cr_2O_7$ which are require for oxidation of three atoms of carbon.

$$\text{2 molecules of } K_2Cr_2O_7 \xrightarrow{\text{Release}} 6(O) \xrightarrow{\text{oxidize}} 3C$$

$2(294)$ g $K_2Cr_2O_7 = 3(12)$ g carbon

49 g $K_2Cr_2O_7$ (1000ml of 1N solution) = 3g carbon

(Equivalent wt. of $K_2Cr_2O_7$ is 49)

1000 ml of 1N $K_2Cr_2O_7$ = 3 g carbon

1 ml of 1N $K_2Cr_2O_7$ = 0.03 g carbon

Regents

1) Potassium dichromate solution (1N): Dissolve 49.04 pure crystal of $K_2Cr_2O_7$ in distilled water and dilute to 1 liter.

2) 0.5N ferrous sulphate solution: Dissolve 139 g $FeSO_4$ (A.R. grade) in distilled water and add 15 ml conc.H_2SO_4 and dilute to 1litre. Ferrous ammonium sulphate can also be used. To prepare 0.5N solution of FAS dissolve 196 g of salt in 800 ml distilled water containing 20 ml concentration, H_2SO_4 and dilute to 1 liter
3) Con. Sulphuric acid: Not less than 96% purity.
4) Orthophsphoric acid : 85%
5) Diphenylamine indicator: Dissolve 0.5g diphenylamine in a mixture of 100 ml concentration H_2SO_4 and 20ml water.
6) Ferroin indicator (0.025 N): Dissolve 1.485g ortho-phenanthroline monohydarate and 0.695g $FeSO_4.7H_2O$ in water. Dilute to 100 ml (During titration colour of the solution changes from dull green to chocolate red). The indicator is also available as prepared solution. Addition of 3 to 4 drops of this indicator is sufficient.

(Note: Ortho-phosphoric acid or sodium fluoride is not required when ferroin solution is used as an indicator).

Procedure:

0.5 to 1.0g finely ground soil sample passed through 0.5mm sieve without loss was transferred into a 500 ml conical flask. 10 ml of 1N potassium dichromate solution was added by means of pipette followed by 20 ml conc. H_2SO_4 with measuring cylinder. The content of the flask was shook for a minute or two and set aside on an asbestos sheet for exactly half an hour. At the end of the period, 200 ml distilled water, 10 ml ortho-phosphoric acid and 1 ml diphenylamine indicator were added. The contents were titrated with std. ferrous ammonium sulphate till colour flashes from blue violet to brilliant green. Similarly, a blank is run without soil.

3.11 Tabulated summary of data obtained from interviews

Data obtained from interviews with farmer and results of soil analysis are given in Table 7 below.

Table 6: Summary of farmers interviewed

Villages	**Shiroli**		**Chincholi**		
Name of farmer	**Bhimrao Khartade**	**Ramesh Khartade**	**Lata Milmile**	**Chandrashekhar Nirbhude**	**Maroti Zade (chemical farm)**
Farm size (ha)	5.2	5.2	6.9	6	2
Type of Agricultural Practice	Organic, except for the field of wheat	Completely organic. Agricultural production output is very low	Completely organic. Agricultural production output is very low	Half of the farm is managed organically and the other half is managed conventionally.	A conventional farm
Type of Soil	Red soil	Red soil	Black cotton soil	Black cotton soil	Black cotton soil
Slope percentage	2 types of slopes: 1-3 % and 3-5%.	2 types of slopes: 1-3% and 3-5%.	1 type of slope: 1-3%	Flat	Flat
Total number of crops	17	13	3	9	2

Villages	Shiroli		Chincholi		
Name of farmer	**Bhimrao Khartade**	**Ramesh Khartade**	**Lata Milmile**	**Chandrashekhar Nirbhude**	**Maroti Zade (chemical farm)**
Number of cattle	1 cow, 1 calf, 2 bullocks, 1 buffalo, 1 sheep and goat	4 bullocks 5 cows	4 bullocks 7 cows	5 cows, 2 calves, 2 buffalos Dung from animals around the area	0
Number of adopted Techniques	13 techniques	13 techniques	13 techniques	13 techniques	2 techniques
Adopted techniques					
Raising of soil bonds.	Yes	Yes	Yes	No	No
Preparation and use of FYM (Farm Yard Manure).	Yes	Yes	Yes	Yes	No
Preparation and use of vermin-compost.	Yes	Yes	Yes	Yes	No
Incorporation of agro-waste in the soil instead of burning	Yes	Yes	Yes	Yes	No
Conducting seed germination test	Yes	Yes	Yes	Yes	No
Treatment of	Yes	Yes	Yes	Yes	yes

Villages	**Shiroli**		**Chincholi**		
Name of farmer	**Bhimrao Khartade**	**Ramesh Khartade**	**Lata Milmile**	**Chandrashekhar Nirbhude**	**Maroti Zade (chemical farm)**
seeds with mixture of cattle dung, cattle urine and ant hill soil					
Sowing across the slope	Yes	Yes	No	No	No
Use of different mixed cropping patterns	Yes	Yes	Yes	Yes	No
Deep hoeing accounting for rainwater harvesting	Yes	Yes	Yes	Yes	yes
Use of Sanjeevak- a fermented product of cattle dung, cattle urine and jaggary which acts as a organic growth promoter	Yes	No	Yes	Yes	No
Use of vermiwash as a growth booster	Yes	No	Yes	Yes	No
Use of cattle	Yes	Yes	Yes	Yes	No

Villages	Shiroli		Chincholi		
Name of farmer	**Bhimrao Khartade**	**Ramesh Khartade**	**Lata Milmile**	**Chandrashekhar Nirbhude**	**Maroti Zade (chemical farm)**
urine + Neem leaf extract for pest management					
Use of trap crops	No	Yes	No	No	No
Leaving weeds on the farm for in situ composting during rainy season instead of putting it on the bunds	No	Yes	yes	Yes	No
Introduction of perennials in the system in form of planting tree samplings	No	Yes	Yes	Yes	No
Development of farm ponds.	Yes	No	No	No	No
Use of bird perches	No	yes	yes	No	No
The year in which farmers converted to organic	2006	2003	2004	2003 (half of the farm)	Converted to organic for two years and reverted to chemicals
Reason (s) for	He had noticed	With chemical	To improve soil	Cost of	He initially

Villages	Shiroli		Chincholi		
Name of farmer	**Bhimrao Khartade**	**Ramesh Khartade**	**Lata Milmile**	**Chandrashekhar Nirbhude**	**Maroti Zade (chemical farm)**
Conversion	that chemical farming was destroying the soil structure in his farm. He believed that by converting to organic farming the soil quality in his farm will be enhanced and production improved. He also believed he will be able to reduce costs of production and labour effort.	farming, the soil structure was degraded. Mr khartade wanted to increase the fertility and quality of the soil and to get rid of the pests on his farm. He believes by adopting organic farming practices, practiced by his forefather for generations, he will be able to achieve these benefits on his farm.	quality	production of chemical farming has resulted in huge debt. To avoid further debt, and to reduce risk profit loss because of crop failure, he converted half of his farm to organic. With organic farming, he uses local and on-farm inputs. He only uses chemical input on half of his farm.	converted to organic because of debt problems, but quickly reverted to chemical farming because he was scared organic farming methods will produce lower yields and he will be able to pay off his debts.
Challenges during conversion	No challenges	No challenges	Pests were a problem in the first 2 years.	No challenges	No challenges
Change in soil	1 year	1 year	3 years	2 years	-----

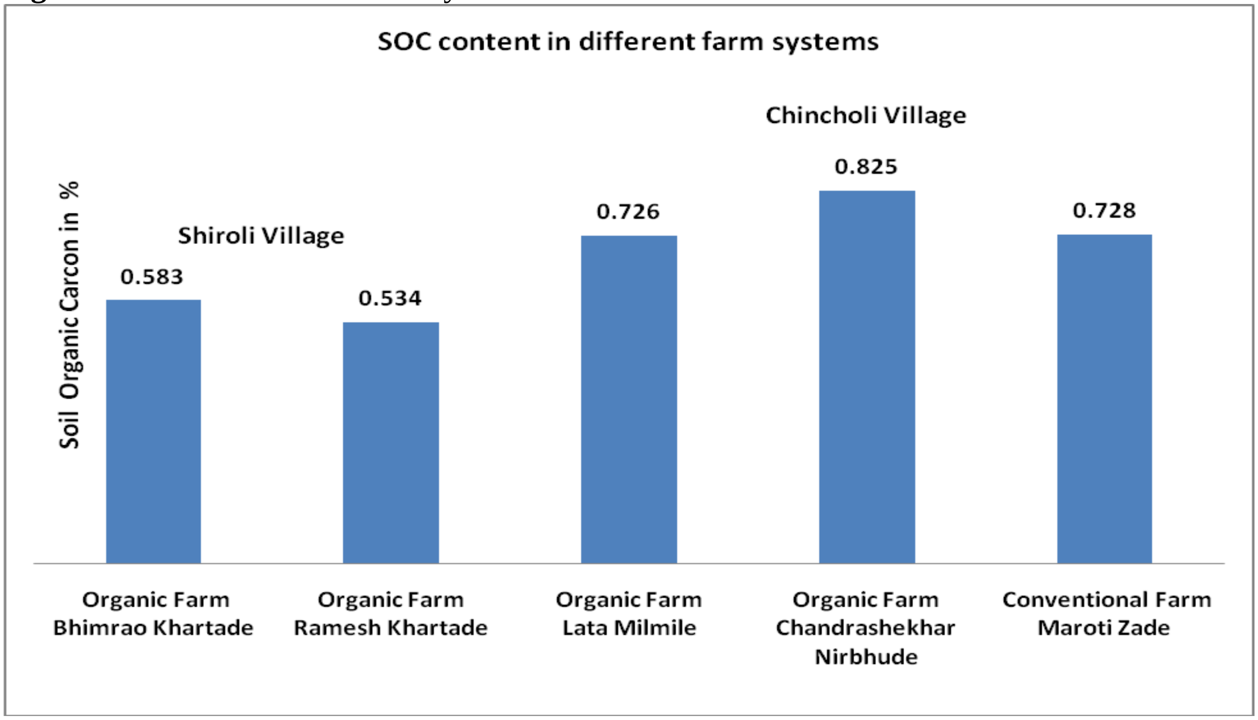
Villages	Shiroli		Chincholi		
Name of farmer	**Bhimrao Khartade**	**Ramesh Khartade**	**Lata Milmile**	**Chandrashekhar Nirbhude**	**Maroti Zade (chemical farm)**
properties was noticed after how long					
Land tillage	Yes: with Bullocks	Yes: with bullocks	Yes: with bullocks and a tractor	Yes: initially with tractor now with bullocks	Yes: with a tractor
Chemical application	Chemicals are only applied on the field of wheat. The rest of the field is organic.	Zero chemical application	Zero chemical application	Chemical application on half of the field. The other half in organic.	The entire farm is applied with fertilizers, pesticides and herbicides 3 times after every 21 days
Water source	1 well	No water sources, harvested rain water	1 well	No water source	No stable water source
Irrigation techniques	Sprinkler irrigation	Flood irrigation	Sprinklers	Rain-fed irrigation	Minor irrigation
Trees	Different types of trees across the slope, the most prominent is the Neem tree	Different types of trees across the slope, the most prominent is the Neem tree	Different types of trees across the slope, the most prominent is the Neem tree	Mostly Neem trees are planted	No tress

Villages	**Shiroli**		**Chincholi**		
Name of farmer	**Bhimrao Khartade**	**Ramesh Khartade**	**Lata Milmile**	**Chandrashekhar Nirbhude**	**Maroti Zade (chemical farm)**
Soil Organic Carbon (%)	**0.583**	**0.534**	**0.726**	**0.825**	**0.728**

3.12 Results

A whole range of SOC levels was recorded in the different farm systems. The difference in SOC content in the five farms ranged from above 0.8 percent to less than 0.6 percent. The two farm systems with the lowest SOC content are located in Shiroli village and the three farms with the highest SOC content are located in Chincholi village.

Figure 10 SOC in different farm systems



The farm managed under sustainable agricultural techniques contained the highest SOC content than the four farm systems. The conventional farm contains the second highest SOC content, followed by an organic farm with a difference of 0.002 percent.

3.12.1 SOC content in Chandrashekhar Nirbhude's farm

The six hectare farm contains the highest SOC levels. Two different management practices are followed on this farm. Half of the farm is managed under conventional farming practices and the other half (converted in 2003) is managed with thirteen sustainable techniques. Due to time constraints, SOC content on the conventional managed field was not analyzed. Soil samples were only collected for analysis only from the organic part of the farm.

The SOC content on the organic field is related to the direct application of organic inputs, which include- FYM from the nine cattle, plant residue from nine crops, biomass from perennials, weed in-situ, incorporation of agro-waste, vermicompost, application of sanjeevak and vermiwash. In addition, Mr Nirbhude collects FYM from the local villages and these represent additional carbon inputs to his farm.

In addition to management practices, SOC content is a product of complex interactions between climate, soil type, and topography. Because Mr Nirbhude's farm is flat, topography in terms of farm position and slope aspect had no bearing on the SOC level on this farm. Management practices are significant sources of SOC content on this farm.

3.12.2 SOC content Maroti Zade's farms

The conventional farm contains the second highest SOC content (0.728 percent). The high SOC level can be explained by high application of chemical inputs. Because only two types of crops (cotton and pigeon pea) are grown, it means there is lower residue return to the soil. The only two sustainable techniques adopted are deep hoeing and seed treatment. Because the slope gradient on this farm is zero the slope effect on the SOC content is significantly less.

3.12.3 SOC content in Mr. Lata Milmile's farm

The SOC level in Mr Milmile's farm is the third highest. Sources of organic input on this farm are- FYM from eleven cattle, vermicompost, plant residues from the three crops, agro-waste, weed in-situ, application of sanjeevak and vermiwash. In total thirteen sustainable techniques form part of the management practice.

Mr Milmile’s farm is characterized by a 1-3 percent of slope. SOC content on this farm is highly comparable to the SOC contents in the two farms with zero slope gradients. This might mean that the overall slope effect on the SOC content is minimal if not null.

3.12.4 SOC content in Mr. Bhimrao Khartade’s farm

Mr B. Khartade’s farm is managed with thirteen sustainable techniques. Sources of organic inputs on this farm are plant residues from seventeen crops, FYM from seven cattle, agro-waste, and application of sanjeevak, vermicompost, and vermiwash. SOC content on this farm was found to be the second lowest. This may be attributed to these factors:

- There are two types of slopes (1-3 and 3-5 percent); as a result, there is a high probability of topsoil and nutrient loss through erosion, leaching, and volatilization.

3.12.5 SOC content in Ramesh Khartade’s farm

Organic amendments in Mr R Khartade’s farm are crop residue from thirteen crops, FYM from nine cattle, agro-waste weed in-situ, and composting. He has adopted thirteen sustainable techniques. The SOC content on this farm is the lowest of all the four farms.

Possible factors that might have resulted in lower SOC content

- The farm is characterised by two types of slopes (1-3 and 3-5 percent), which might result in loss of topsoil and nutrients loss through erosion and other forms of soil degradation.
- Loss of nutrient through increased aeration and soil disturbance because of tillage practices.

3.13 Discussion

The aim of this study was to compare four farms managed under sustainable farming techniques with a farm managed under conventional agricultural practice. The study further compared how different management practices have affected SOC levels in the five farms.

The results showed that the SOC content across the five farms is generally low. The organic carbon content of the soil barely exceeds one percent. This might be as a result of previous management practices that are heavily dependent on chemical inputs (Ramakrishna, 1992:1-2). SOC on the five farms ranged from 0.53 to 0.825 percent.

Under farms managed with sustainable farming techniques, farmers adopted the same number but different sustainable techniques. Out of seventeen farming techniques introduced, farmers adopted only thirteen. Techniques were adopted based on their practical utility, ease of adoption, lower labour effort and the availability of on-farm and local resources in implementing those techniques. Eight sustainable techniques introduced to farmers by Dharamitra are expected to promote the return of carbon to the soil in the form of organic matter, and they are sanjeevak, vermiwash, compost vermin-compost, FYM, weed in-situ, agro-waste utilization for incorporation in the farm or composting, and mixed cropping patterns. Other techniques are to curb erosion, for pest management, seed treatment, rain water harvesting, and water storage.

The rate of soil carbon sequestration is not solely dependent on the number of sustainable techniques adopted, but depends on several factors including climate, slope gradient, soil type, type of crops and management practices. The duration of management practices will also influence carbon content. The interactive affects of these factors determines the SOC content recorded on each farm. The percent of SOC on a farm managed under sustainable farming techniques was found to be higher than the percent of SOC on the conventional farm.

SOC was higher on the farms with zero slope gradients and lower in the two farms characterized by two types of slope (1-3 and 3-5 percent). Results obtained suggest that the SOC content in the two farms, though not quantified might be affected by the slope. Another factor that might have attributed to the low SOC content in the two farms is the soil type. The three farms that contain the highest SOC are located in Chincholi village and the two farms with the lowest SOC are located in Shiroli village. Soils in Shiroli are red type of soils and those in Chincholi are black-cotton soils.

Great limitation in comparing SOC content across the different farms is that no data exists on the history of SOC content on the farms. The available data only represents one point in time and it is therefore not possible to draw any conclusions about the rate or direction of carbon change. Although farming practices may be influencing rates of carbon sequestration, the soil carbon content of the farms is likely to have differed prior to the adoption of sustainable agriculture. Even so, the results show that the farm that adopted sustainable techniques contain higher SOC levels than the farm that does not employ such practice.

Whilst it cannot be empirically proven, farmers who have adopted sustainable agricultural technique in addition to improved SOC in their farms, have communicated improvement in yields, soil structure, farm net profit, and less pest problems and diseases than farmers still farming with chemicals.

Sustainable farming practices that can be expected to enhance carbon levels are:

- Contour bunding,
- Agro-waste utilization for incorporation in the farm or composting,
- In situ composting of weeds,
- Sowing across the slope,
- Seed germination test, Seed treatment (using cattle dung + urine +ant hill soil),
- Preparation and use of compost and vermin-compost,
- Mixed cropping patterns,
- Adoption of gap filling management
- Deep hoeing
- Use of Sanjeevak
- Use of vermiwash
- Use of cattle urine and Neem spray
- Use of trap crops
- Use of bird perches
- Tree planting on farm bunds
- Establishment of farm ponds

3.14 Conclusion

The Green Revolution approach brought about many challenges in the Indian agricultural sector, and those challenges are still of great concern even today. Combined effect of degraded natural resource base, lower return of organic matter leading to lower soil fertility, declining agricultural yields, high costs of inorganic production inputs, and hence the decreased profit margin has led many farmers into poverty and indebtedness. As consequent Indian farmers are committing suicides at a terrible rate. As a way of assisting farmers to overcome these intertwined challenges, Dharamitra in the past five years has been working earnestly with farmers, educating and encouraging them to convert to a more sustainable agricultural production system that will augment yields, increase farm profits and improve the agronomic ability of the soil. With the aid of local farmers, Dharamitra developed, through incorporating elements of both traditional knowledge and modern agricultural science, a package of unsophisticated and low costs sustainable agricultural techniques, which are completely based on the use of locally available resources.

By adopting sustainable techniques, farmers have reduced the dependency on external capital intensive inputs and taken total advantage of the local resources. Their farms are no longer simplified, but complex with more diverse cropping patterns and greater number of cattle than the conventional farms. These aspects were clearly demonstrated on this case study. All four farmers under sustainable farming techniques had greater number of cattle, and grew large number of crops under diverse cropping patterns. In contrast, the farm under conventional farming practice didn’t have any livestock and grew only two types of crops. Accordingly, a farm under sustainable farming techniques contained the highest SOC content than the farm under conventional farming practices. Sustainable farming techniques heavily rely on local knowledge and resources and are an alternative path to agricultural productivity that is more environmentally sound, affordable, and profitable. As such, farmers in India are converting to sustainable agriculture.

CHAPTER 4: A COMPARISON OF ORGANIC AND CONVENTIONAL VEGETABLE PRODUCTION IN STELLENBOSCH, SOUTH AFRICA

4.1 Introduction

This study involves the comparison of an organic vegetable farm with an adjacent conventional one and focuses on the impact of the two different production systems on the SOC levels.

The study focused on answering the following critical questions:

1. How do management practices differ between the two farms?
2. How have SOC levels been affected by the two different farm management systems, one organic and one conventional?
3. How have other soil chemical parameters been affected in the two farms?

4.2 Description of the organic and conventional farm and management practices employed

The two farms lie adjacent to one another, across a public road, as shown in Figure 11. The organic farm is down slope from the conventional one, and although it is on slightly steeper slopes, the individual beds have been levelled. Landscape position and slope are not likely to affect soil conditions differently on the two farms. Soils are all granite derived duplex soils. Upper soil horizons are course textured sands with a clay content of less than five percent. The upper, sandy horizons are underlain by a clay rich horizon. Soil sampling was confined to the upper sandy horizons.

Figure 11: The Conventional and Organic farm systems

The organic farm was initially managed under conventional farming practices and it was cultivated with tobacco until early 1980s. For nineteen years, the ten hectare farm-land lay fallow and in 1999 under *Go-Organic at Spier*[3] production resumed, this time under organic agriculture management practices. The following organic amendments were employed; horse and chicken manure application, and compost. In the very same year, the farm was automatically certified organic by Ecocert. During the first three years, the farm was struck with fungal and pest diseases. To address the problem, organic sprays made from extract derived from berries of a syringa tree – *Melia Azedarach* were used, and are still being used today. The poison in the berries- triterpenoid provides protection against pests.

[3] Go Organic at Spier is a joined venture with seven emerging farmers, Eric being one of them; together own 27.5% of the business. 100 hectares of the land Spier used to lease from the local municipality is used by the company and it is funded by the government's Land Reform Credit Facility. The farm is now one of South Africa's largest commercial organic farms, fully certified by Ecocert and supply fresh vegetables to leading supermarkets in the Western Cape and overseas. In 2002, Eric took over the management of the farm but only 10% of it.

The five hectare conventional farm had since been farmed with chemicals. No other management practices have been employed ever since. The conventional farm was previously cultivated with tobacco until 1980s.

Figure 12: The Organic Farm

Figure 13: The Conventional Farm

Table 7: Summary of the management practices on the organic and conventional farms

	Organic Farm	**Conventional Farm**
Farm size	10 hectares	5 hectares
Types of crops produced	Carrots Broth beans Broccoli Spinach Beetroot Green beans Lettuce Onions Potatoes Tomatoes Peppers Squashes Varieties of legumes	Lettuce Potatoes Green beans
Number of crops produced	13	3
Cropping Patterns	Intercropping	Monocropping
Crop rotation plan	No specific crop rotation plan is followed. However, certain crops are planted on specific plots on certain time of the year.	No specific plan followed.
Trees	Numerous trees	Zero trees
Tillage Equipment	Disc and crop.	Tractor
Weed management and control	Weeds are incorporated into the soil system.	The weeds are completely removed from the system.
Pest control	Through application of organic spray made from Syringa tree.	Through application of synthetic pesticides and fungicides
Irrigation	Sprinkler irrigation Daily irrigation. About 15-30 minutes in summer.	Sprinkler irrigation Daily irrigation. About 15-30 minutes in summer.
Seeds	Buys most of the seeds from the market and a small quantity is produced organically on the farm.	All seeds are bought from the market.

Table 8: Detail Record of Production inputs

		Organic Farm Mr. E. Swart	Conventional Farm Mr. P Stone
a.	**Organic amendments application**		
i.	Surface mulching	No	Yes
ii.	Compost Application	Yes	No
iii.	Vermicomposting/ Earthworm composting	Yes	No
iv.	Crop residue return	Yes	Yes
v.	Organic manure	Yes	No
vi.	Green manure	Yes	No
vii.	Under sowing	No	No
viii.	Chicken manure	Yes	No
b.	**Agrochemical application**		
i.	Insecticides	No	Yes
ii.	Herbicides	No	Yes
iii.	Fungicides	No	Yes
iv.	Fertilizers	No	Yes
v.	Synthetic growth stimulants	No	Yes
c.	**Burning Activities**		
i.	Burning activities of agro waste	No	Yes

Differences in management practices on the organic and conventional farm were significant. There was greater levels on both species diversity and abundance on the organic farm compared to the conventional farm. The organic farm had more trees per field boundary while the conventional farm had zero trees. The trees on the organic farm of which ninety percent are Syringa trees, serve many purposes. As established from Mr Swart- the organic farm manager, trees create an agriculturally conducive micro-climate that favours the sustainability of cropping systems. Shade from the canopy created by trees reduces solar gain at the surface of the soil helping the soil to retain moisture. Trees also function as wind breakers. Windbreakers fight wind related soil erosion and crops desiccation (Thakur, 2006:224). Organic mulches, cover crops, and crop residues also serve these purposes very well. Organic mulches, cover crops, and crop residues in addition supply a large portion of nutrients input (Norman, 1954:287). Compost application applied every time before planting is also an excellent source of nutrients.

Significant number of legume species was also found on the organic farm. These serve as nitrogen sources, which in turn increases soil quality and the potential of carbon sequestration (Frederick & Thompson 2005:222). Weeds and legumes enhance biodiversity, the quality, and quantity of residue return and SOC pool (Lal, 2004:12). Thirteen crops are grown on the organic farm under intercropping pattern, and the residues that accumulate after harvesting are not removed, but incorporated into the soil to increase SOC. The conventional farm had less crop diversity, only three crops are grown, and these indicate a low return of organic matter. Monocropping and biomass burning are prevalent on the conventional farm.

In addition to the fertilizer and pesticide management approach practiced on the conventional farm, wood mulch is used to slow erosion of topsoil (Gehring, 2008:146), however erosion is not a problem in the conventional farm as the farm is proportionally even. Wood mulch prevents weeds and unwanted plants from growing on the farm floor and keeps the soil moist.

4.2 Materials and Methods

4.2.1 Site Description

The farms are located in Lynedoch, Stellenbosch at 33˚ 55’12” South and 18˚ 51’ 35 East. The local climate is mediterranean in character with an average annual winter rainfall between 600 mm and 800 mm. The average summer temperature is 29 ºC and average winter temperature is 19 ºC.

4.2.2 Sampling Design

Based on thorough background knowledge of the area and an assessment of the general site conditions, inherent, natural soil conditions are known to be fairly uniform across the investigated areas. Samples from the two farms were taken within 500 meters of each other.

Soil sampling was done on the 19th of May 2008. Composite soil samples were collected to accommodate the natural variation in soil parameters that is likely to occur. Between twenty and thirty sub-samples, collected from more or less equally spaced positions along transects across each plot made up the composite sample for that plot. Soil samples were collected from one depth interval of between 0 and 15 centimetre using a stainless steel auger.

Samples were taken to compare three different treatments: actively cropped soils on the organic farm; fallow soils on the organic farm; and actively cropped soils on the conventional farm. Ten composite samples were collected from plots P1, P2, P3 F4, F7, F10, H4, H7, and H10.

Sampling positions were recorded with GPS. Each letter represents one of the three treatments that were compared, with the different plots being replicate samples for that treatment.

Figure 14: Conventional Farm with plots P1, P2, P3, & P4

Figure 15: Organic Farm with plots F4,F7,F10,H4,H7 & H10

4.3 Soil Analysis

Soil samples were sent to Bemlab laboratory in Strand for chemical analysis. The following analyses were performed: Organic carbon using the Walkley-Black standard method; pH in a 1M solution of KCl at a 1:4 ratio of soil to solution; resistance in a saturated paste using a standard cup; Bray II extractable P; exchangeable cations, Ca, Mg, Na and K extracted with Ammonium acetate at pH7, Trace elements Cu, Zn, Mn, B extracted with 1M HCl: H using the standard Eksteen method, used in the Western Cape and stone (>2mm) by dry sieving.

4.4 Statistical Analysis

Statistical analysis of the soil analysis results was conducted by the Centre for Statistical Consultation at the University of Stellenbosch. Statistically significant differences between the three treatments were tested for all analyses soil parameters and are reported in the results below according to the Bonferroni test with significance at a p value of less than 0.05.

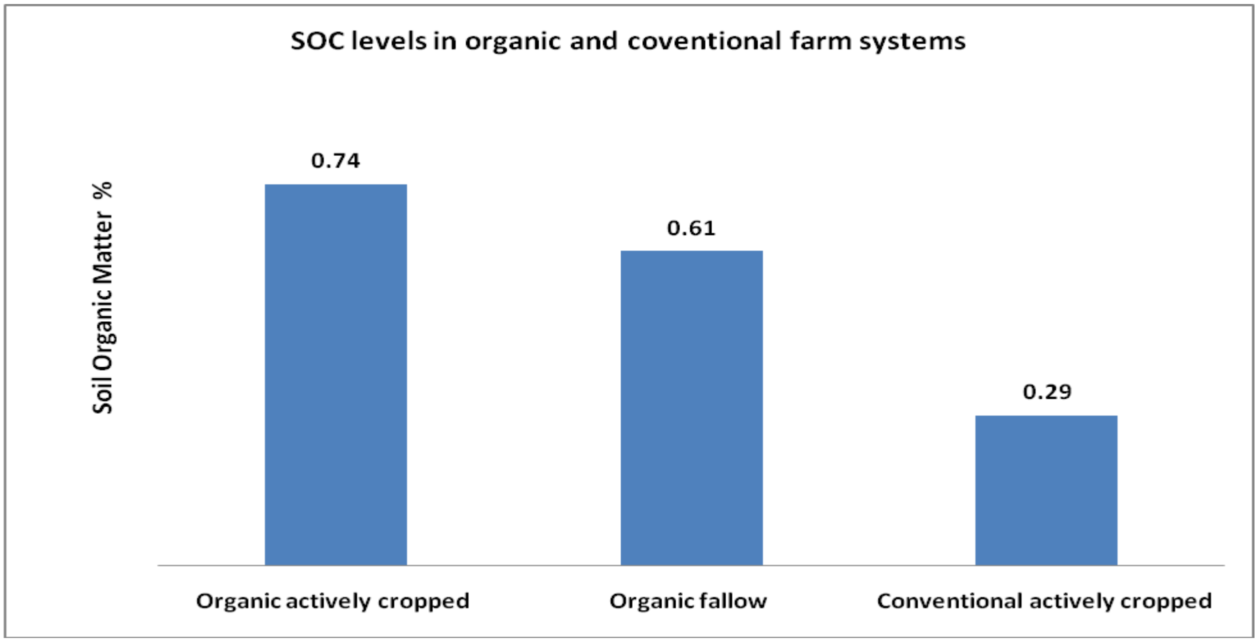
4.5 Results

The results of the soil analysis for the three different treatments are given in Table 10 below. Table 10: Comparison of soil parameters for the three tested treatments. Listed values are the means for the 3 or 4 replicates.

Table 9: Comparison of soil parameters for the three tested treatment

Soil parameter	**Organic actively cropped**	**Organic fallow**	**Conventional actively cropped**
Organic carbon (%)	0.74	0.61	0.29
pH (in KCl)	6.4	5.8	4.9
Resistance (ohm).	1953	2117	4340
Acidity (H+) (cmol/kg)	0.00	0.38	0.52
Stone (>2mm) (%)	53	24	23
Phosphorus (mg/kg)	294	304	206
Exchangeable potassium (mg/kg)	141	67	58
%K	10.3	4.3	6.7
Exchangeable sodium (cmol/kg)	0.07	0.05	0.03
%Na	1.91	1.09	1.38
Exchangeable calcium (cmol/kg)	2.46	2.85	0.93
%Ca	70.0	69.9	48.4
Exchangeable magnesium (cmol/kg)	0.63	0.63	0.20
%Mg	17.8	15.3	11.0
T value	3.52	4.07	1.81
Copper (%)	0.65	1.12	0.71
Zinc (%)	10.3	11.1	4.9
Manganese (%)	8.4	8.9	1.8
Boron (%)	0.31	0.16	0.09

Figure 16: SOC levels in organic and conventional farms



The SOC content on the organic farm was approximately three times higher than the SOC content on the conventional farm. The SOC content on the organic farm ranged from 0.61 percent on the organic fallow to 0.78 percent on the organic actively cropped fields. SOC content on the conventional farm was very low with 0.29 percent.

High T-value was recorded on the organic treatment and as a result, higher ratios of exchangeable sodium, potassium, calcium, and magnesium were recorded on the organic farm than on the conventional farm.

Phosphorus, an essential nutrient for plants was higher across the three treatments. Other macronutrients-potassium, sodium, calcium, and magnesium were higher on the organic actively cropped and the organic fallow treatments than on the conventional actively cropped treatment.

Trace elements differed across the three treatments. The difference in the manganese and zinc content on the two organic treatments was insignificant, however, differed greatly with zinc and manganese contents recorded on the conventional farm. Copper content, which was found to be high throughout, differed slightly across the three treatments. Low boron levels were recorded on the organic fallow and the conventional actively cropped treatments.

4.6 Discussion

The aim of the soil sampling and analysis was to test whether management practices used on the organic farm have led to a difference in soil organic matter content as well as other soil parameters, compared to the practices used on the conventional farm.

For the purposes of this study, inherent soil conditions are presumed to be the same. This is justified by fairly thorough background knowledge of the soils of the area, based on past soil investigations, as well as an assessment of the surface and landscape conditions across the two sites. It is therefore assumed that organic matter levels between the two farms were the same before the onset of the different management approaches ten years ago, and that their differences now are as a result of that management.

Separate samples on the organic farm were taken from actively cropped soils and from soils, which have been fallow for some time. This was to test whether the organic practices have influenced SOC levels, in relation to fallow land where these practices are not being applied. The

SOC levels of fallow land where no crop is removed and is under a cover of vegetation (weeds in this case), can be expected to maintain or increase over time. The low number of replicates (3 or 4) may result in differences not being statistically significant, even if there is reasonable numerical difference between the means.

The organic actively cropped soil had significantly higher carbon content than the conventional one, which is likely to be a result of the organic matter enhancing practices that have been applied on the organic farm. There is no significant difference in carbon content between the actively cropped and the fallow land of the organic farm.

The pH of the organic farm is significantly higher than the conventional farm, which is below optimum. It is not known whether liming material was added on the organic farm or if the difference in pH can be related to other practices. The pH differences are also related to the differences in calcium level and calcium percentage.

The T-value of the organic farm soils differs significantly from the T-value of the conventional farm. The T-value is the sum of exchangeable cations and is similar to (but not identical to) the cation-exchange capacity. Organic matter contributes significantly to the cation-exchange capacity, particularly in sandy soils, which have a low cation-exchange capacity. The difference in T-value is likely to be as a result of the difference in organic matter content. The cation exchange capacity influences the amounts of exchangeable cations. The higher it is, the higher will be the exchangeable Ca, Mg, K and Na. The higher organic matter and T-value is also likely to explain the measured differences between Ca, Mg, and Na.

There are no differences between treatments in the major plant nutrients, phosphorus and potassium. Phosphorus levels are extremely high across the two farms. These levels are not natural and must be a result of previous over-fertilization, probably when the soils were used for tobacco production. The potassium levels are also fairly high and may well reflect past fertilization.

In terms of trace elements, there are no differences in copper and zinc (which is very high throughout), but the organic farm has higher manganese and the actively cropped organic has higher boron than both the organic fallow and the conventional, both of which have less than adequate levels of boron. Therefore, there may be significant levels of boron in one of the organic amendments being used on the organic farm.

There is a significant difference in stone content between the organic actively cropped and the other two treatments, which indicates an inherent soil difference, but one which is not likely to influence the chemical parameters of importance to this study.

4.7 Conclusion

The results showed that management practices on the organic farm result in higher SOC content than those on the conventional farm. The amount of SOC level on the organic farm is a function of the composition and quantity of crop residue, vermin compost, and compost and other organic material returned to the soil. Organic farming practices enhance soil nutrients and are likely to improve species diversity and crop yield. Conversely, conventional agricultural practices discourage the return of carbon in the form of organic matter. The system heavily relies on chemical inputs and promotes practices such as biomass burning that result in losses of SOC.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

Entrenched mismanagement of fragile and finite soil resources within the agricultural sector has led to a dramatic reduction in soil organic carbon, with consequent negative alteration in the soil's physical properties in terms of aggregate stability, water-holding capacity, and porosity, chemical properties in terms of soil nutrient content, and biological properties in terms of soil microbial activities and biodiversity. This has caused a significant decline is soil quality and a reduction in food production. The historic loss of carbon from soils through flux of carbon dioxide to the atmosphere is estimated at 66 Pg (Lal *et al*, 2001:7-9) with current rate of loss of approximately 0.8 Pg C/yr (Wigley and Schimel,2000:95). In contrast, soil carbon sequestration provides a partial, medium-term countermeasure to help reduce current unsustainable emission trends through the creation and protection of stable carbon sinks. However, rates of carbon sequestration cannot be maintained indefinitely. The long-term sustainable solution lies in a carbon free development paradigm that will keep atmospheric carbon dioxide concentrations at acceptable levels. In agriculture, this is depended on the large scale adoption of sustainable agriculture that will help sequester carbon in the form of soil organic matter.

Agricultural use of soil influences the SOC content. Watson *et al*. (1996) estimated that 0.4-0.8 Pg C/yr could be sequestered in agricultural soils globally by implementation of sustainable farming practices. This is about ten percent of the global anthropogenic production of carbon dioxide for the year 1990 [6 Pg C/y].

Data presented in this study revealed that farms managed under sustainable management practices generally contain higher SOC than farms managed under conventional farming practices. The organic farm in Lynedoch had higher SOC content than the adjacent conventional farm. The same results are true for the India case study. A farm managed under sustainable techniques contained the highest SOC than the four farms.

The SOC levels on the organic and sustainable farm systems in India and Lynedoch are directly related to the management practices employed and the amount of organic matter added to the soil in a form of crop residues, farm yard manure, composts, vermin compost, and other organic materials. However, the effectiveness of management practices in increasing SOC is depended on local factors such as climate, topography, and soil types. The India case study is a good example. The four farms were managed with equal number of techniques but because of the difference in the location, soil types and topography of the farms, a range of SOC levels were recorded. The study showed that farms with a zero slope gradient contained the highest SOC levels followed by a farm with a 1-3 percent type of slope. The two farms characterized by (1-3 and 3-5 percent) slopes contained the lowest SOC content. The difference in SOC content in the farms is attributed to the combined effect of these factors. All farms in this study contained very low levels of SOC. The SOC contents were below one percent. Consequently, the potential of soil carbon sequestration in these soils is very high.

In comparing the two farms in Lynedoch, no significant difference was established on the major plant nutrient, phosphorus. In addition, micro-nutrients, manganese, and boron were higher on the organic than on the conventional farm. Potassium, phosphorus and zinc were very high on both farms, probably because of previous management practices. Magnesium, calcium and potassium exhangable-cation were high on the organic farm as compared to the conventional farm. Therefore, it can be concluded based on the Lynedoch study that organic farming practices naturally enhances plant nutrients.

Another important aspect revealed by the study is that farms under sustainable agriculture paradigm exhibited higher levels of species diversity and abundance as compared to conventional farms and these translates to increased complexity, thus rendering the organic farm in Lynedoch and the four farms in India potentially sustainable than the two conventional farms.

Additional on-farm and off-farm benefits associated with sustainable agriculture

a. Improvement in soil quality which equates to a reversal of soil degradation, soil fertility enhancement and resilience (this occurs through an improvement in soil properties and functions such as aggregate stability, porosity, moisture retention, infiltration, nutrient retention, soil biodiversity, biological activity and nutrient cycling). This will enhance food and fibre productivity without deteriorating the functional capacity of the soil. The agricultural system will be more resilient and will therefore meet the food and fibre needs of the current and future generations in a more sustainable manner.
b. Reduction in current agricultural energy use. According to Sauerbeck (2001), RMPs (Recommended management practices) will lead to a 10-40 percent reduction in the present agricultural energy requirement, and therefore reduce GHGs and CO_2 emissions. They will

minimize synthetic fertilizer, pesticide, and herbicide use and thus reduce dependency on fossil fuels.

c. Restore degraded ecosystems and soil systems. Lal *et al.* (1995) estimated that degraded soils could sequester 0.1 to 1 Pg C/y, depending on management.

d. Help countries who have acceded to the Kyoto protocol reach their emission reduction targets.

e. Buy us time, in terms of CO_2 emissions, while alternative fossil fuels take effect.

The importance of adopting sustainable agriculture

Sustainable agriculture can be adopted and applied universally, but in order to derive optimum advantage of this farming practice, significant knowledge of local soil resources, topography, and climatic factors must be established and well understood. To achieve this involves tapping into both farmer and scientist knowledge to bring forth information that will help farmers understand the complex interrelationship of farm systems. In India, the Dharamitra organization is working with farmers to develop site-specific management practices that coincide with the local environment and conditions. Positive results have been achieved in that regard.

It is every country's responsibility to generate own site-specific agriculture management practices that will continuously enhance the integrity of local natural resources. As with India, this is critical for South Africa whose agricultural resource base is under serious threat. According to Villiers *et al*, (2005) 60 percent of soils in South Africa have low soil organic matter and hence are conducive to low productivity and degradation. Using the international norm of 0.4 hectares per person, South Africa on its 14 million hectares of arable land, can only feed 35 million people. Today the vulnerable and degrading soils are feeding over 48.7 million people. This poses serious challenges that make promotion of sustainable agriculture and soil carbon sequestration important. The existing governmental (e.g. the Landcare program) and institutional support is inadequate. Currently there is no formal policy in place to promote sustainable agriculture and no incentives to encourage farmers to farm with local resources. In India, the National Program for Organic Production (NPOP) is supporting and promoting sustainable agriculture. Through the program, 339113 hectares of land has been brought under sustainable farming practices. In South Africa only 5000 hectares of land is farmed under sustainable practices.

Of course, the approach that the South African government will take in promoting sustainable agriculture might differ from the approach that the Indian government has pursued, mainly because the agricultural context in the two countries is completely different. South African agriculture is dualistic in nature with a larger percentage of commercial than subsistence farming. In India, agriculture is more subsistence. Consequently, it was easy for the government and NGOs to encourage farmers to convert. Farmers were motivated to change by their own socio-economic circumstances and the deteriorating nature of their farms. In South Africa, the motivation might be different and that might make it difficult to encourage farmers who are mainly commercial farmers to farm sustainably. However, this is considered possible. What is needed is more institutional support from the government and NGOs. It will also require indigenous knowledge of farming and a collaborated scientific effort to pave the way towards agricultural sustainability.

Research and development priorities

The following are recommendations of research and development priorities related to sustainable agriculture and soil carbon sequestration.

- Benefits of sustainable agriculture have been well documented in this paper. However, institutional barriers to adoption still exist. Those barriers need to be identified, documented and addressed both at a local and international level.

- Promotion of sustainable agriculture is the responsibility of all stakeholders: policymakers, researchers, farmers and the local people. Each group must contribute (in knowledge and expertise) and work as a collective to promote sustainable agriculture.

- Conversion from conventional to sustainable agriculture can result in short term reduction of yields. Therefore, governments must be prepared to compensate farmers for their losses during the transition period.

- Institutional support to farmers should be increased.

- Support to agricultural research should be increased. Funding for sustainable agriculture and soil carbon sequestration should be expanded.

- Scientific divisions or institutes should be established to monitor soil quality. Provincial and national targets for improving soil quality must be set-up.

- Carbon markets should be developed that give direct economic value to sequestered soil carbon.
- Both disciplinary and interdisciplinary research in agricultural science should be promoted and local institutions that will facilitate this effort must be established.

- In order to promote soil carbon sequestration and reverse forms of soil degradation, research in South Africa must focus on investigating local soil and climate conditions and establish site-specific management practices that are appropriate to South Africa.

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APPENDICES

Appendix 1: Questionnaire for farmers in India

Interview schedule for a study entitled:

Type of Agricultural system:

Name of farmer:

Date of the Interview:

Instructions: Fill in the corresponding answer on the dotted lines

A. Farm profile

1. How many acres/hectares is your farm?

……

2. Can you describe the soil in your farm?

……

3. What are the degrees of slopes found in the farm?

……

4. Describe your farm cropping history?

……

5. What is the type of irrigation technique followed in your farm?

…………………………………………………………………………………………………….

6. Are there animal in your farm?

………………………………………………………………………………………………………

7. Are there trees in your farm?

………………………………………………………………………………………………………

B. Farm history and conversion

8. How long have you being farming?

………………………………………………………………………………………………………

9. What type of agricultural management practices do you practice in your farm?

………………………………………………………………………………………………………

This section to be answered by conventional farmers

10. Why are you still farming with chemical?

……………………………………………………………………………………………………..

11. Do you have any pest or disease problems in your farm?

……………………………………………………………………………………………………..

12. What do you do to get rid of pests in your farm?

………………………………………………………………………………………………………

13. Have your yield improved when compared to the previous year?

………………………………………………………………………………………………………

14. How often do you apply chemical inputs?

……………………………………………………………………………………………………..

15. By how many folds have you increased the chemical application in your farm over the years?

………………………………………………………………………………………………………

16. Do you apply manure or any other organic amendment in your farm?

………………………………………………………………………………………………………

17. What are your views on organic/sustainable agriculture?

………………………………………………………………………………………………………

18. Do you intend converting to sustainable/organic agriculture? Yes or No (Please provide reasons for both answers)

………………………………………………………………………………………………………

This section to be answered only by organic farmers

19. Why did you convert to organic/sustainable farming?

………………………………………………………………………………………………………

20. What management practices did you employ during the conversion period?

……………………………………………………………………………………………………..

21. What kind of problems did you face during the conversion period? And what did you do to remedy them?

………………………………………………………………………………………………………

22. Did you convert the entire holding at once?

………………………………………………………………………………………………………

C. **Sustainable management techniques**

23. How many techniques were introduced to you?

……………………………………………………………………………………………………

24. How many techniques have you adopted?

……………………………………………………………………………………………………

25. Reason for not adopting other techniques?

……………………………………………………………………………………………………

Appendix 2: Questionnaire for farmers in Lynedoch

Interview schedule for a study entitled:

Type of Agricultural system:

Name of farmer:

Date of the Interview:

Instructions: Fill in the corresponding answer on the dotted lines

A. Farm History

1. Describe the cropping history of you farm?

…………………………………………………………………………………………………....

2. How many acres/hectares is your farm?

……………………………………………………………………………………………………

This section must be answered by the organic farmer

3. When did you convert to organic farming?

……………………………………………………………………………………………………

4. What are your reasons for conversion?

……………………………………………………………………………………………………

5. Did you have a support base during the conversion?

…………………………………………………………………………………………………

6. When was the farm certified?

…………………………………………………………………………………………………

7. The farm was certified by which certification agency?

…………………………………………………………………………………………………

8. Did you convert the entire farm holding at once?

…………………………………………………………………………………………………

9. Which management practices did you employed during conversion period?

…………………………………………………………………………………………………

10. Did you experience any pest or crop disease problems during the conversion period?

…………………………………………………………………………………………………

11. What did you do to fight crop and pest problems?

……………………………………………………………………………………………….

12. Are you currently facing pest and disease problems?

…………………………………………………………………………………………………

This section must be answered by the conventional farmer

13. What are your views about organic/sustainable farming?

……………………………………………………………………………………………………

14. Do you intend converting to organic/sustainable farming? Yes or No (Please provide reasons for both answers)

……………………………………………………………………………………………………

This section must be answered by both organic and conventional farmer

D. Farm profile

15. Describe the soil in your farm?

……………………………………………………………………………………………………

16. Do you have any slopes in your farm?

……………………………………………………………………………………………………

17. Are there animal in your farm?

……………………………………………………………………………………………………

18. Are there trees in your farm?

……………………………………………………………………………………………………

E. Cropping system

20. What types of crops do you grown in your farm?

……………………………………………………………………………………………………

21. Do you grow legumes in your farm?

……………………………………………………………………………………………………

22. What type of cropping system do you employ in your farm?

……………………………………………………………………………………………………

F. Crop Rotation

23. Do you follow a crop rotation plan?

……………………………………………………………………………………………………

24. What type of plan is that (is it a three part, four or five part rotation)?

…………………………………………………………………………………………………..

G. Tillage systems

25. What type of tillage methods do you practice in you farm (no-till, mulch tillage, ridge tillage, reduced tillage) or conventional tillage?

……………………………………………………………………………………………………

26. What tillage equipment do you employ?

……………………………………………………………………………………………………

27. How often do you till your farm?

…………………………………………………………………………………………………

H. Weed management and control

28. Do you have weeds in your farm?

…………………………………………………………………………………………………

29. What strategies to employ to control/manage weeds in your farm?

…………………………………………………………………………………………………

I. Pest control

30. What methods do you employ to control pests?

…………………………………………………………………………………………………

J. Irrigation

31. What type of irrigation techniques do you employ in your farm?

…………………………………………………………………………………………………

32. What is the quantity of water used?

…………………………………………………………………………………………………

33. How often do you irrigate your farm?

……………………………………………………………………………………………………

Instruction: Tick on the corresponding answer

K. Detail Record of inputs

	Organic Farm Mr. E Swart	**Conventional Farm** Mr. P Stone
a. Organic amendments application		
i. Surface mulching		
ii. Compost Application		
ii. Vermicomposting/ Earthworm composting		
v. Crop residue return		
v. Organic manure		
vi. Green manure		
ii. Under sowing		
b. Agrochemical application		
i. Insecticides		
ii. Herbicides		
ii. Fungicides		
v. Fertilizers		
v. Synthetic growth stimulants		
c. Burning		
i. Burning of waste organic material		